# Embedded Systems

## Week 3: System Design with Sensors I
## Baremetal


**Dr. Vecdi Emre Levent**

# Instructors

Assist. Prof. Dr. Vecdi Emre Levent

Email : emre@levent.tc

emre.levent@marmara.edu.tr

Web: www.levent.tc

# System Design with Sensors I - Baremetal

## How to Build an Embedded System?

- Buttons
- Sensors
  - Temperature
  - IMU
  - GPS
  - …
- Communication Interfaces
  - UART
  - SPI
  - I2C
  - Ethernet
  - …
- RF Transceiver

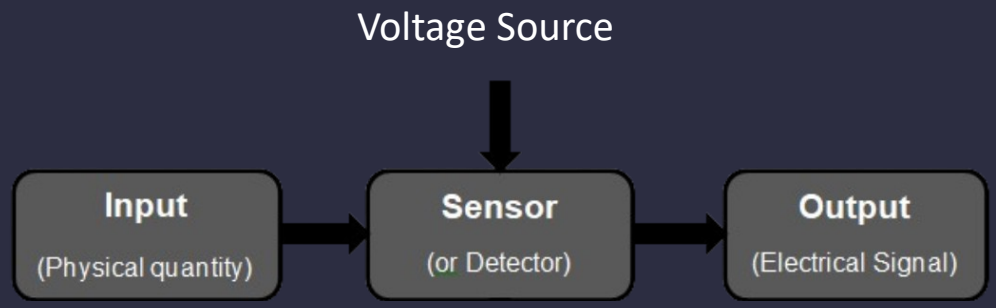

- LEDs
- Motors
- Communication Interfaces
  - UART
  - SPI
  - I2C
  - Ethernet
  - …
- RF Transceiver

# System Design with Sensors I - Baremetal

## Sensors

### Sensor

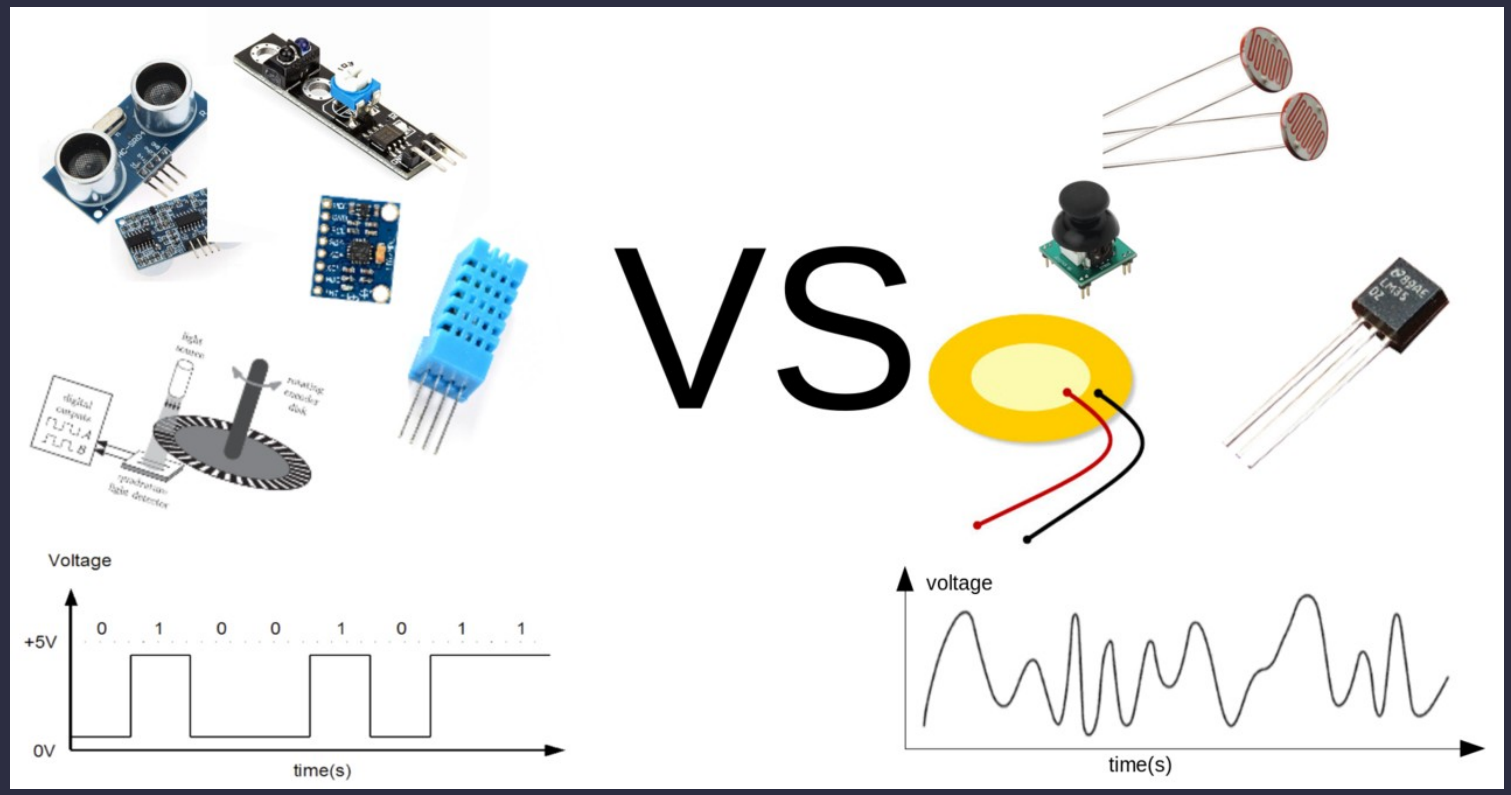
- Device for Detection: A sensor is a device designed to detect changes in physical, chemical, or biological environments.
- Signal Conversion: It converts these changes into electrical signals that can be measured and processed.
- Real-World Interface: Serves as the bridge between the physical world and embedded systems.
- Core Functionality: Enables systems to monitor, control, and respond to environmental variations.



# System Design with Sensors I - Baremetal

## Sensors

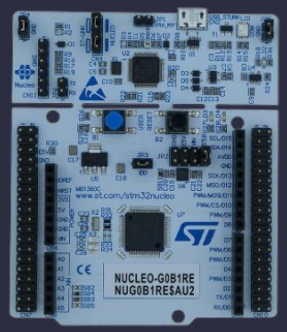
- Sensor Output Types
  - Analog Sensors
  - Digital Sensors
- Sensors Types
  - Temperature
  - Pressure
  - Light
  - Motion
  - Gas
  - GPS
  - Etc…



# System Design with Sensors I - Baremetal

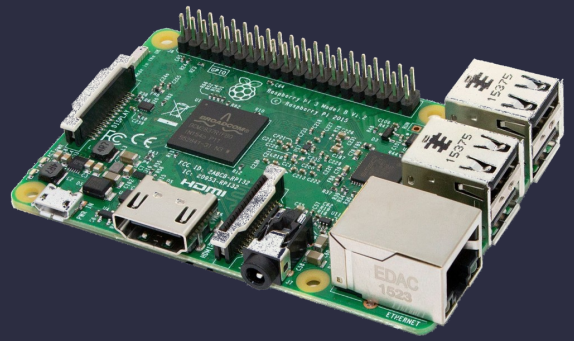
- MCU & MPU Development Boards

Arduino Mega




STM32 Nucleo 64

MCU Based



Rasberry Pi 3

MPU Based

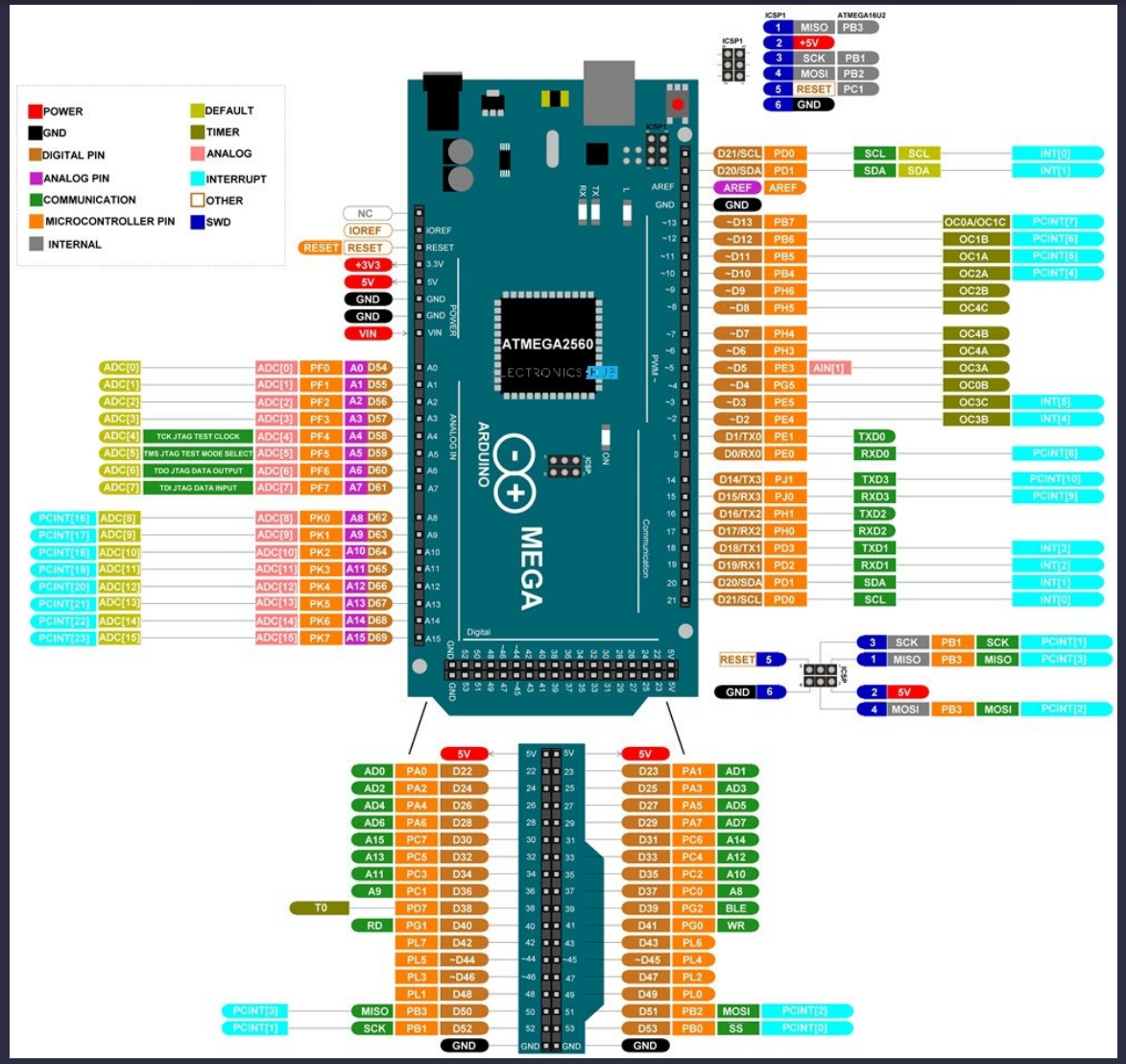
# System Design with Sensors I - Baremetal

- MCU & MPU Development Boards
  - Arduino Mega 2560 Development Board + Extension Card
  - The board accommodates
    - The ATmega2560 microcontroller, which operates at a frequency of 16 MHz. 54 digital input/output pins,
    - 16 analog inputs,
    - 4 UARTs
    - A USB connection,
    - A power jack
    - An ICSP header
    - A reset button.
  - For Details:

https://docs.arduino.cc/resources/datasheets/A000067-datasheet.pdf

# System Design with Sensors I - Baremetal

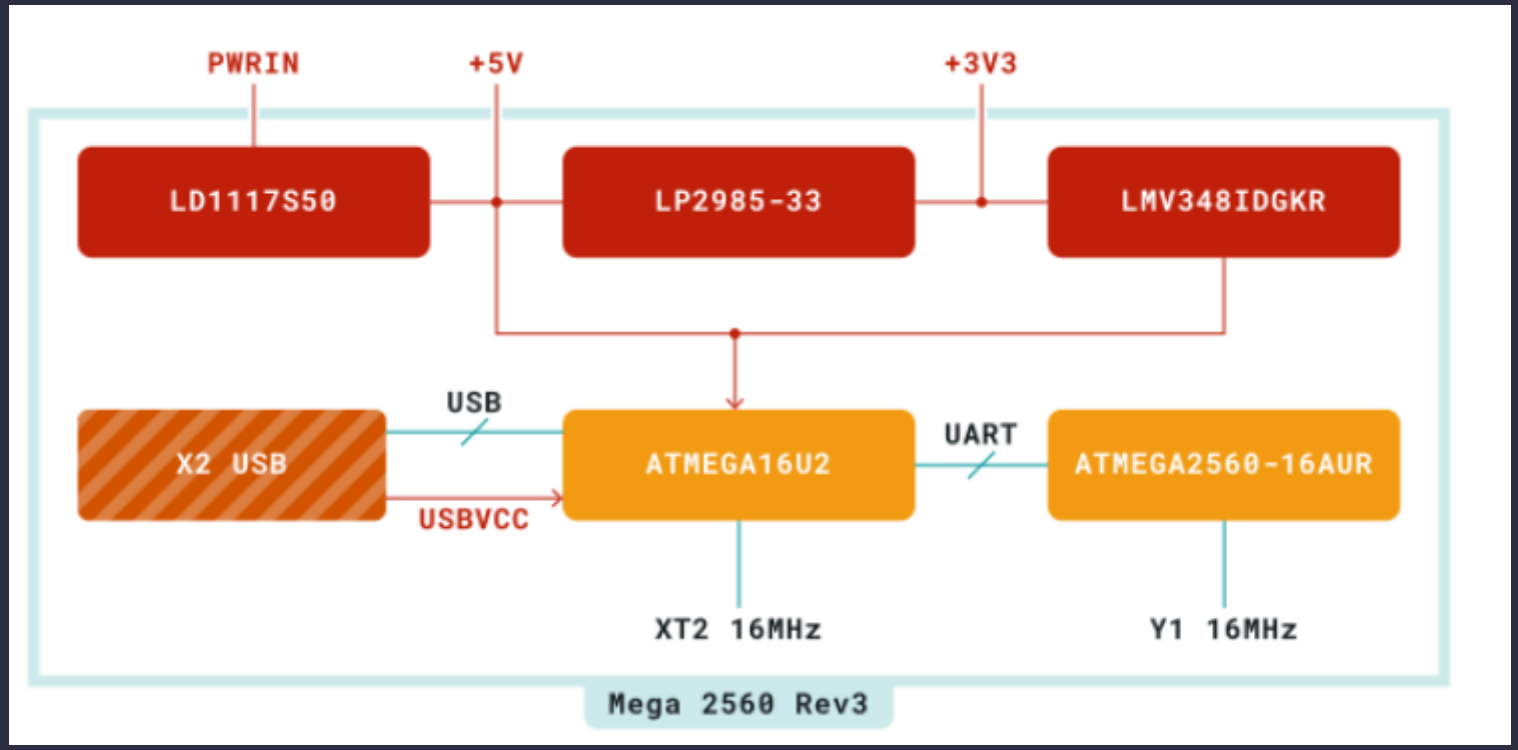
- MCU & MPU Development Boards
  - Arduino Mega 2560 Development Board + Extension Card
  - Board Pinout Diagram



# System Design with Sensors I - Baremetal

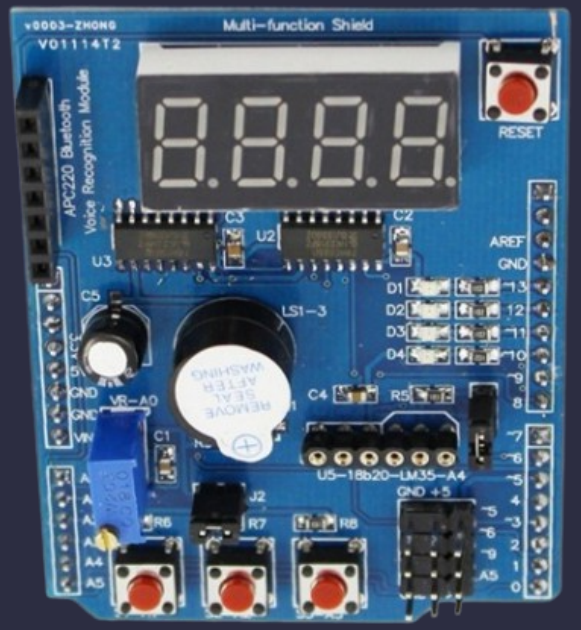
- MCU & MPU Development Boards
  - Arduino Mega 2560 Development Board + Extension Card

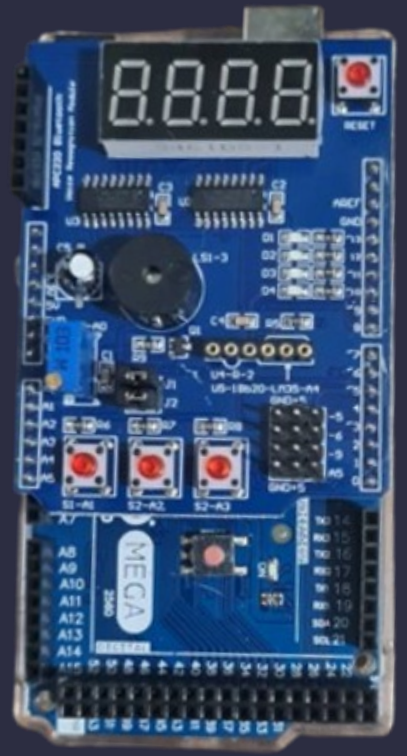
- Board Block Diagram

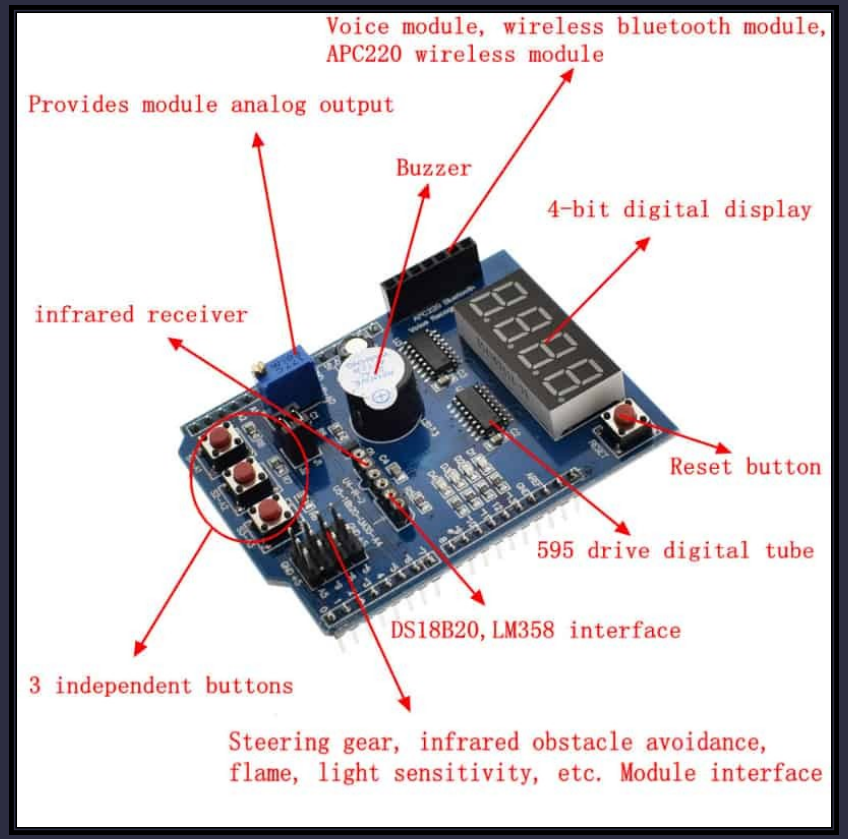


# System Design with Sensors I - Baremetal

- MCU & MPU Development Boards
  - Arduino Mega 2560 Development Board + Extension Card

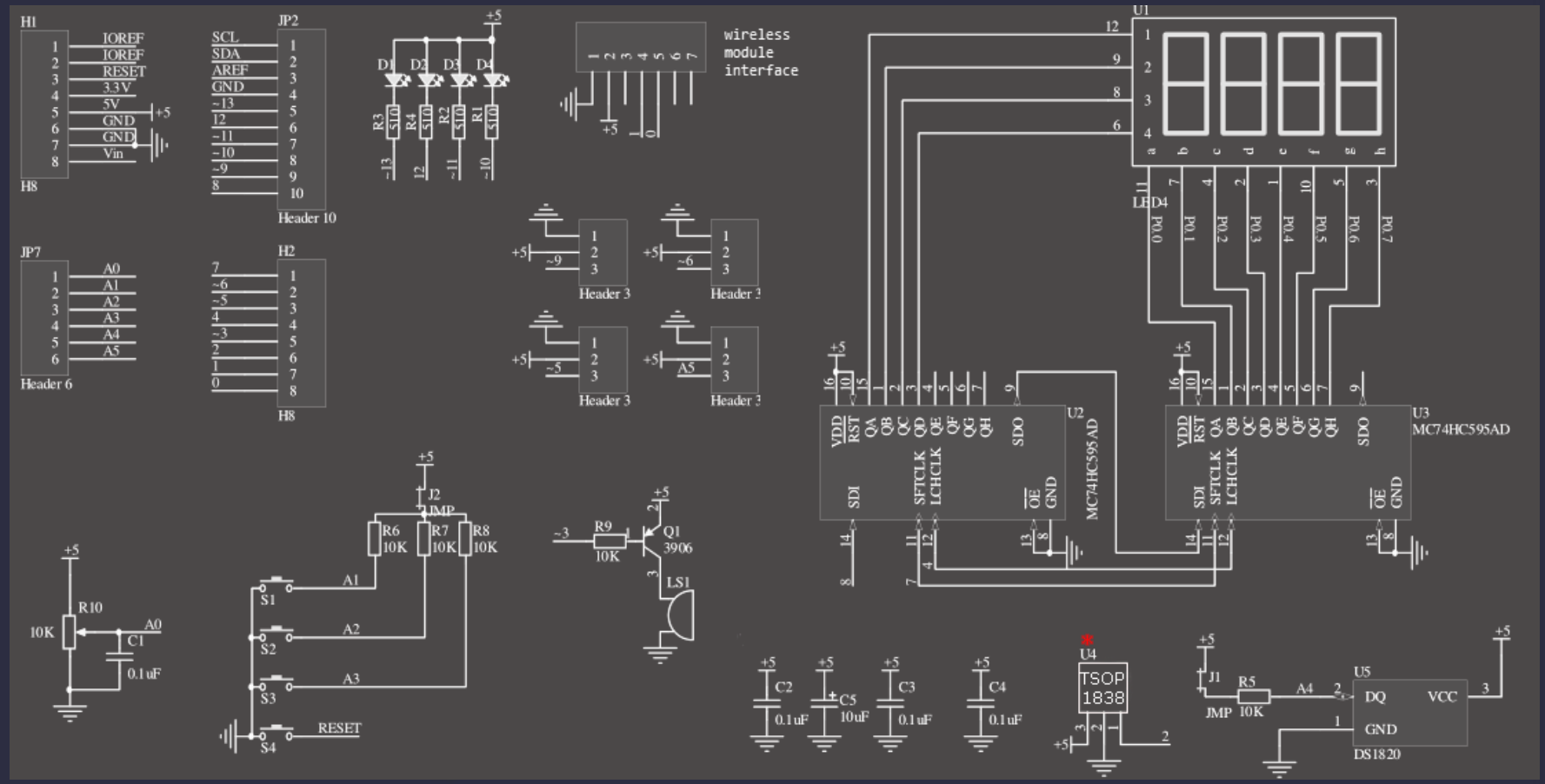


# System Design with Sensors I - Baremetal

- MCU & MPU Development Boards
  - Arduino Mega 2560 Development Board + Extension Card



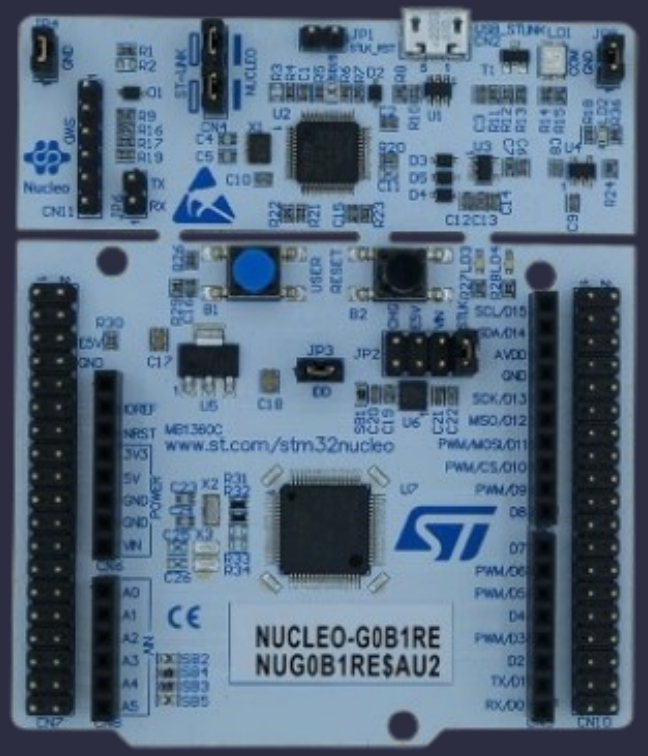
# System Design with Sensors I - Baremetal

- MCU & MPU Development Boards
  - STM32 Nucleo Development Board

  - STM32 microcontroller in LQFP64 package
  - Three LEDs:
    - USB communication (LD1), user LED (LD2), power LED (LD3)
  - Two push-buttons: USER and RESET
  - Two types of extension resources
    - ARDUINO® Uno V3 connectivity
  - ST morpho extension pin headers for full access to all STM32 I/Os
  - Three different interfaces supported on USB:
    - Virtual COM port
    - Mass storage
    - Debug port

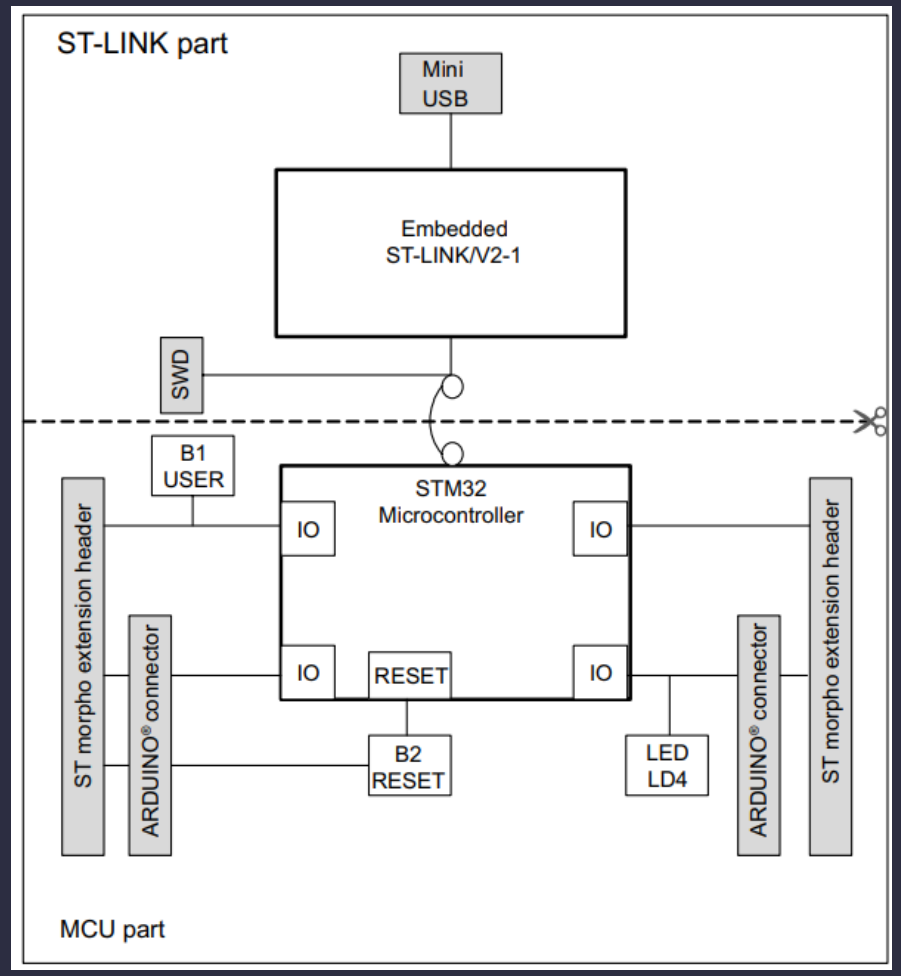
  - For details:

  https://www.st.com/resource/en/user_manual/um1724-stm32-nucleo64-boards-mb1136-stmicroelectronics.pdf



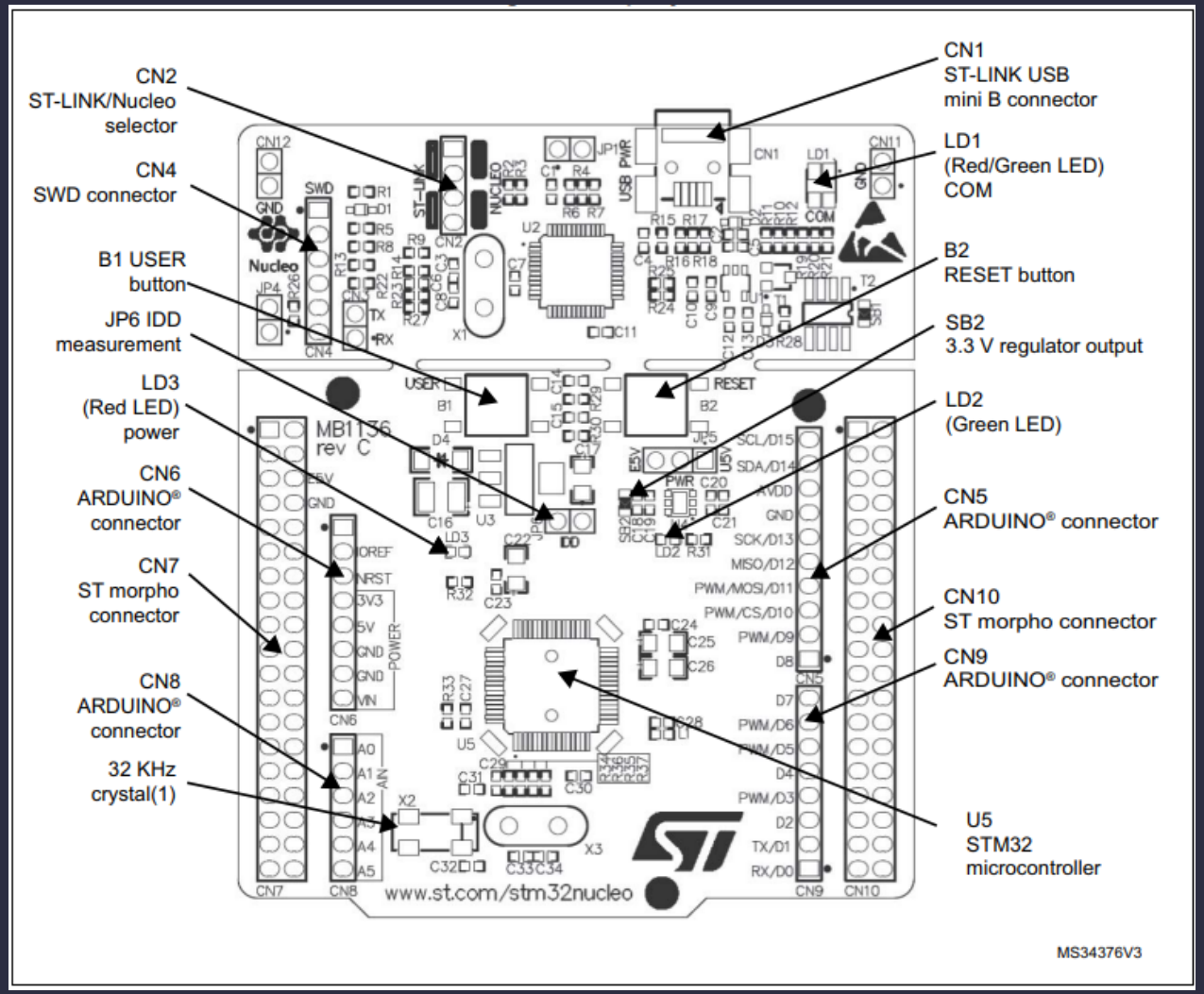
# System Design with Sensors I - Baremetal

- MCU & MPU Development Boards
  - STM32 Nucleo Development Board
  - STM32 Nucleo Board Block Diagram



# System Design with Sensors I - Baremetal

- MCU & MPU Development Boards
  - STM32 Nucleo Development Board
  - STM32 Nucleo Board Block Diagram



# MCU & MPU Architectures, Interfaces

- MCU & MPU Development Boards

- MPU, STM32 Nucleo with Extension Board

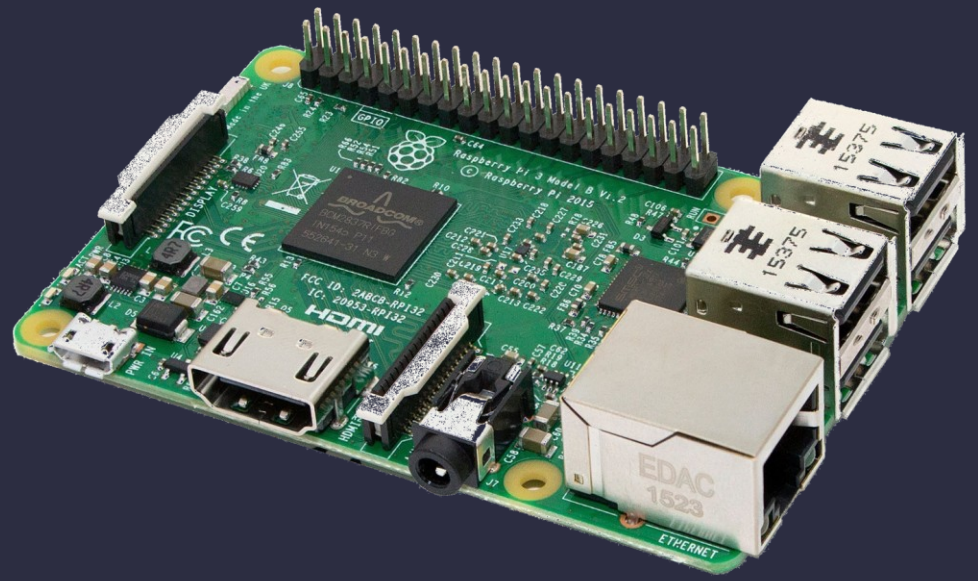
# System Design with Sensors I - Baremetal

- MCU & MPU Development Boards
  - Rasberry PI 3 Development Board

- Raspberry Pi 3 Model B+ has a 64-bit quad-core processor running at 1.4GHz
- Dual-band 2.4GHz and 5GHz wireless LAN
- Bluetooth 4.2/BLE
- Gigabit Ethernet
- USB 2.0
- 1 x full size HDMI
- MIPI DSI display port
- MIPI CSI camera port

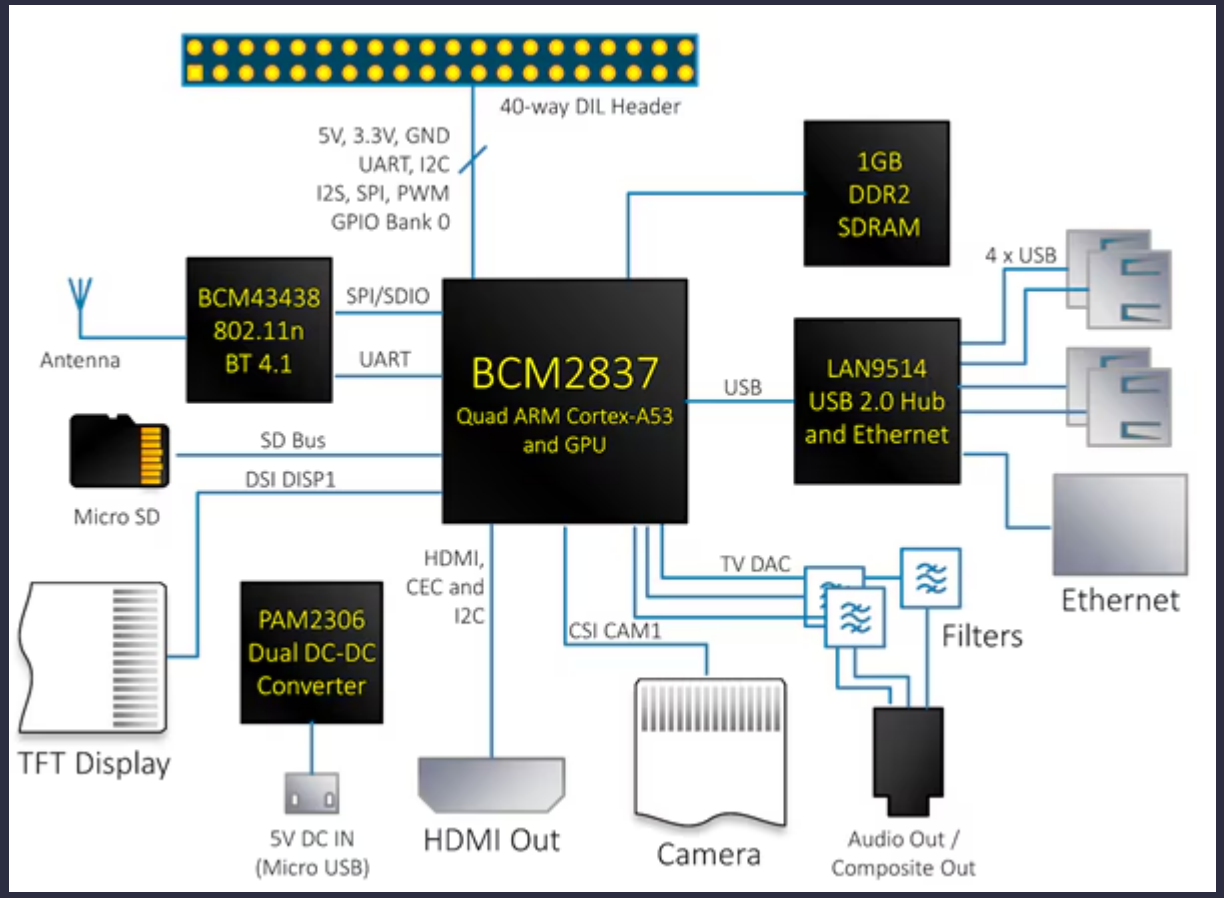
- Details:

https://datasheets.raspberrypi.com/rpi3/raspberry-pi-3-b-plus-product-brief.pdf



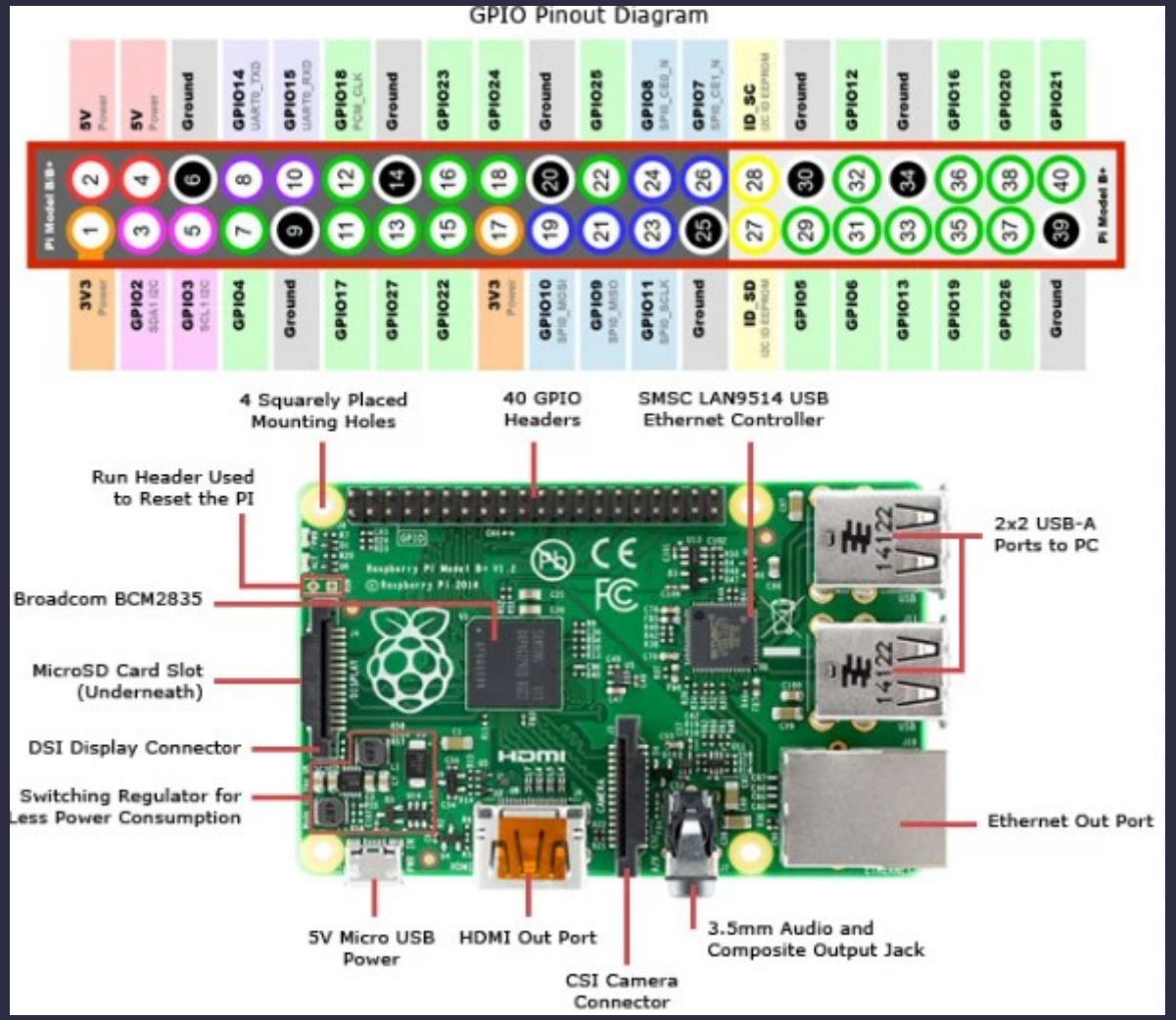
# System Design with Sensors I - Baremetal

- MCU & MPU Development Boards
  - Rasberry PI 3 Development Board
  - Block Diagram



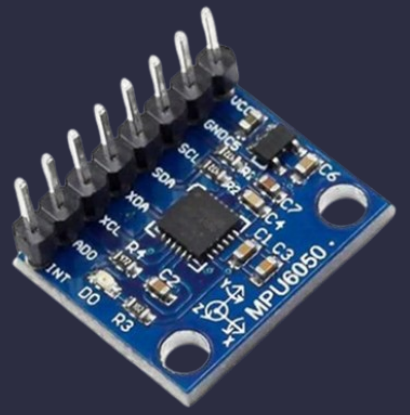
# System Design with Sensors I - Baremetal

- MCU & MPU Development Boards
  - Rasberry PI 3 Development Board
  - Block Diagram

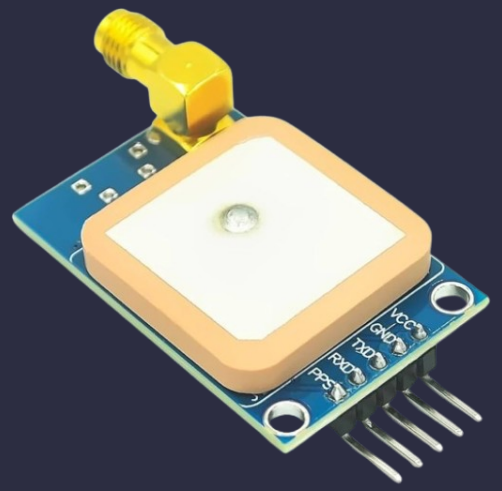


# System Design with Sensors I - Baremetal

- Sensor Development Boards
  - Sensors
  - Use Case Hardwares
  - Gyroscope, MPU6050
  - Laser Distance Measurement, TOF050C
  - GPS, NEO-7M
  - RF Transceiver, Dorji DRF1278DM





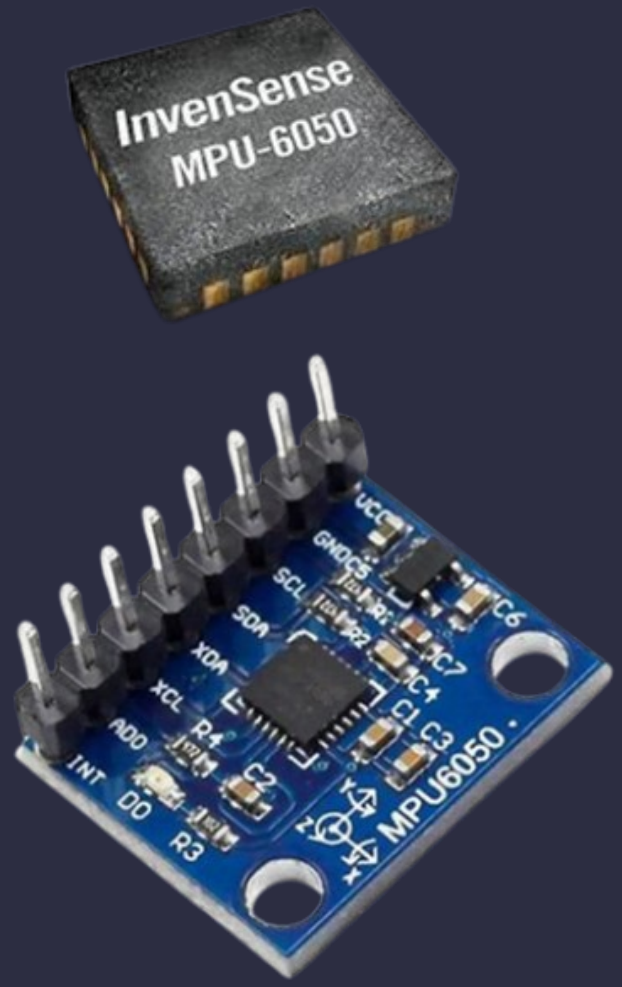



# System Design with Sensors I - Baremetal

- Sensor Development Boards
  - Sensors
  - Gyroscope, MPU6050
  - Voltage: 3-5V
  - Gyro Maximum Degree Measurement: +- 250, 500, 1000, 2000 ° / s
  - Accelerometer: ± 2 ± 4 ± 8 ± 16 g
  - Communication: Standart I²C
  - I2C Address: 0x68
  - Up to 400KHz I2C Speed
  - Details

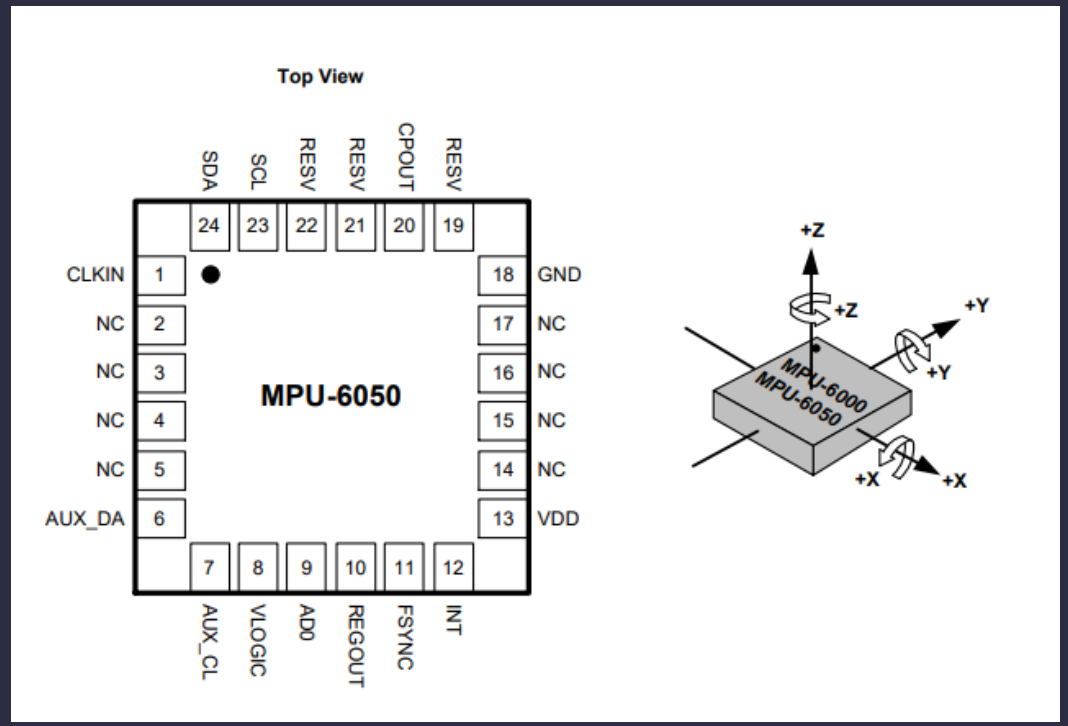
https://invensense.tdk.com/wp-content/uploads/2015/02/MPU-6000-Datasheet1.pdf

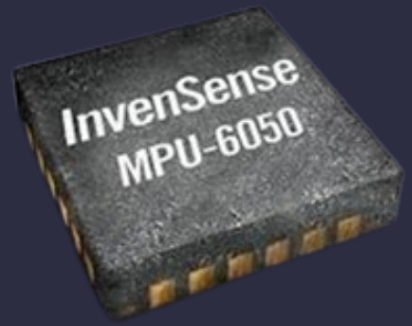
https://invensense.tdk.com/wp-content/uploads/2015/02/MPU-6000-Register-Map1.pdf

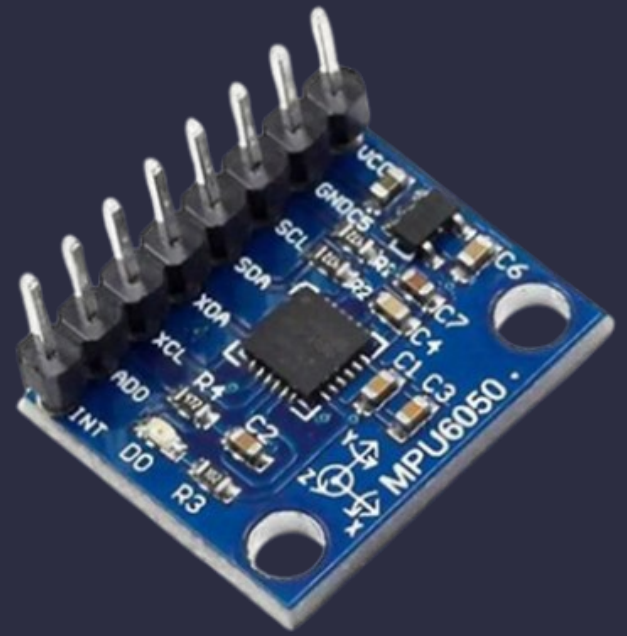


# System Design with Sensors I - Baremetal

- Sensor Development Boards
  - Sensors
  - Gyroscope, MPU6050 I/Os

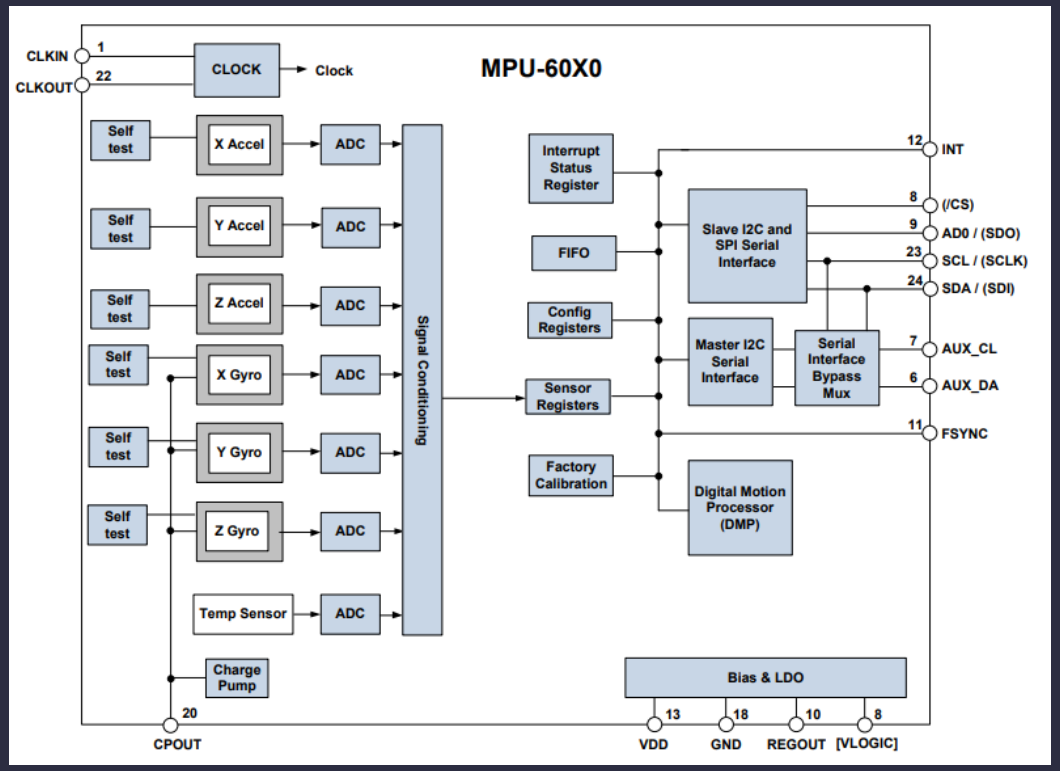


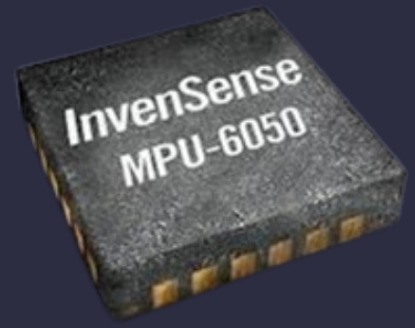



# System Design with Sensors I - Baremetal

- Sensor Development Boards
  - Sensors
  - Gyroscope, MPU6050 Diagram



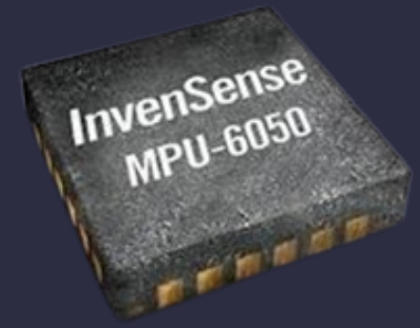



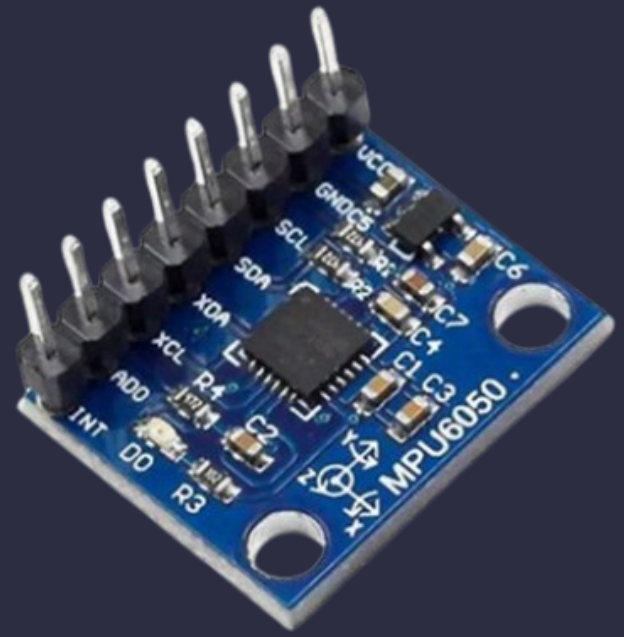

# System Design with Sensors I - Baremetal

- Sensor Development Boards
  - Sensors
  - Gyroscope, MPU6050 Diagram

Interrupt Sources

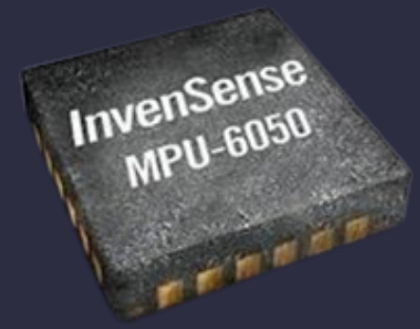
- FIFO Overflow FIFO
- Data Ready Sensor Registers
- I2C Master errors: Lost Arbitration, NACKs I 2C Master



# System Design with Sensors I - Baremetal

- Sensor Development Boards
  - Sensors
  - Gyroscope, MPU6050 Diagram
  - Typical Register Read





*Single-Byte Read Sequence*

| Master | S | AD+W | | RA | | S | AD+R | | | NACK | P |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Slave | | | ACK | | ACK | | | ACK | DATA | | |

*Burst Read Sequence*

| Master | S | AD+W | | RA | | S | AD+R | | | ACK | | NACK | P |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Slave | | | ACK | | ACK | | | ACK | DATA | | DATA | | |

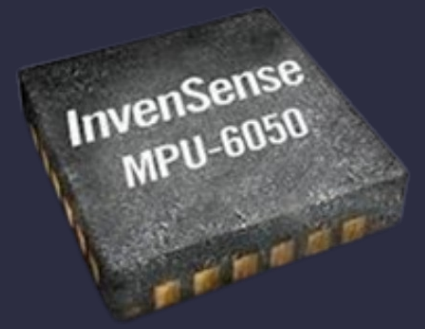
# System Design with Sensors I - Baremetal

- Sensor Development Boards
  - Sensors
  - Gyroscope, MPU6050 Diagram
  - Typical Register Write

| Master | S | AD+W | | RA | | DATA | | P |
|---|---|---|---|---|---|---|---|---|
| Slave | | | ACK | | ACK | | ACK | |

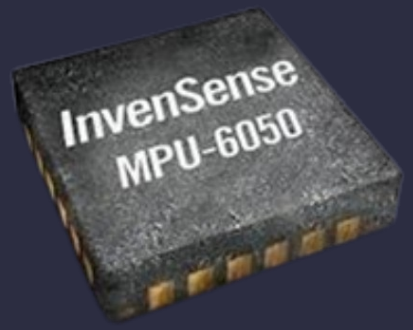
*Burst Write Sequence*

| Master | S | AD+W | | RA | | DATA | | DATA | | P |
|---|---|---|---|---|---|---|---|---|---|---|
| Slave | | | ACK | | ACK | | ACK | | ACK | |




# System Design with Sensors I - Baremetal

- Sensor Development Boards
  - Sensors
  - Gyroscope, MPU6050 Register Space

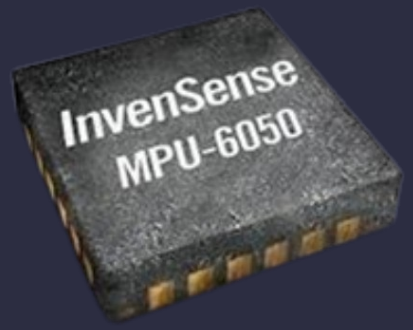




| Addr (Hex) | Addr (Dec.) | Register Name | Serial I/F | Bit7 | Bit6 | Bit5 | Bit4 | Bit3 | Bit2 | Bit1 | Bit0 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0D | 13 | SELF_TEST_X | R/W | XA_TEST[4-2] | | | XG_TEST[4-0] | | | | |
| 0E | 14 | SELF_TEST_Y | R/W | YA_TEST[4-2] | | | YG_TEST[4-0] | | | | |
| 0F | 15 | SELF_TEST_Z | R/W | ZA_TEST[4-2] | | | ZG_TEST[4-0] | | | | |
| 10 | 16 | SELF_TEST_A | R/W | RESERVED | | XA_TEST[1-0] | | YA_TEST[1-0] | | ZA_TEST[1-0] | |
| 19 | 25 | SMPLRT_DIV | R/W | SMPLRT_DIV[7:0] | | | | | | | |
| 1A | 26 | CONFIG | R/W | - | - | EXT_SYNC_SET[2:0] | | | DLPF_CFG[2:0] | | |
| 1B | 27 | GYRO_CONFIG | R/W | - | - | - | FS_SEL [1:0] | | - | - | - |
| 1C | 28 | ACCEL_CONFIG | R/W | XA_ST | YA_ST | ZA_ST | AFS_SEL[1:0] | | | | |
| 23 | 35 | FIFO_EN | R/W | TEMP _FIFO_EN | XG _FIFO_EN | YG _FIFO_EN | ZG _FIFO_EN | ACCEL _FIFO_EN | SLV2 _FIFO_EN | SLV1 _FIFO_EN | SLV0 _FIFO_EN |
| 24 | 36 | I2C_MST_CTRL | R/W | MULT _MST_EN | WAIT _FOR_ES | SLV_3 _FIFO_EN | I2C_MST _P_NSR | I2C_MST_CLK[3:0] | | | |
| 25 | 37 | I2C_SLV0_ADDR | R/W | I2C_SLV0 _RW | I2C_SLV0_ADDR[6:0] | | | | | | |
| 26 | 38 | I2C_SLV0_REG | R/W | I2C_SLV0_REG[7:0] | | | | | | | |
| 27 | 39 | I2C_SLV0_CTRL | R/W | I2C_SLV0 _EN | I2C_SLV0 _BYTE_SW | I2C_SLV0 _REG_DIS | I2C_SLV0 _GRP | I2C_SLV0_LEN[3:0] | | | |
| 28 | 40 | I2C_SLV1_ADDR | R/W | I2C_SLV1 _RW | I2C_SLV1_ADDR[6:0] | | | | | | |
| 29 | 41 | I2C_SLV1_REG | R/W | I2C_SLV1_REG[7:0] | | | | | | | |
| 2A | 42 | I2C_SLV1_CTRL | R/W | I2C_SLV1 _EN | I2C_SLV1 _BYTE_SW | I2C_SLV1 _REG_DIS | I2C_SLV1 _GRP | I2C_SLV1_LEN[3:0] | | | |
| 2B | 43 | I2C_SLV2_ADDR | R/W | I2C_SLV2 _RW | I2C_SLV2_ADDR[6:0] | | | | | | |
| 2C | 44 | I2C_SLV2_REG | R/W | I2C_SLV2_REG[7:0] | | | | | | | |
| 2D | 45 | I2C_SLV2_CTRL | R/W | I2C_SLV2 _EN | I2C_SLV2 _BYTE_SW | I2C_SLV2 _REG_DIS | I2C_SLV2 _GRP | I2C_SLV2_LEN[3:0] | | | |
| 2E | 46 | I2C_SLV3_ADDR | R/W | I2C_SLV3 _RW | I2C_SLV3_ADDR[6:0] | | | | | | |
| 2F | 47 | I2C_SLV3_REG | R/W | I2C_SLV3_REG[7:0] | | | | | | | |
| 30 | 48 | I2C_SLV3_CTRL | R/W | I2C_SLV3 _EN | I2C_SLV3 _BYTE_SW | I2C_SLV3 _REG_DIS | I2C_SLV3 _GRP | I2C_SLV3_LEN[3:0] | | | |
| 31 | 49 | I2C_SLV4_ADDR | R/W | I2C_SLV4 _RW | I2C_SLV4_ADDR[6:0] | | | | | | |
| 32 | 50 | I2C_SLV4_REG | R/W | I2C_SLV4_REG[7:0] | | | | | | | |
| 33 | 51 | I2C_SLV4_DO | R/W | I2C_SLV4_DO[7:0] | | | | | | | |
| 34 | 52 | I2C_SLV4_CTRL | R/W | I2C_SLV4 _EN | I2C_SLV4 _INT_EN | I2C_SLV4 _REG_DIS | I2C_MST_DLY[4:0] | | | | |
| 35 | 53 | I2C_SLV4_DI | R | I2C_SLV4_DI[7:0] | | | | | | | |
| 36 | 54 | I2C_MST_STATUS | R | PASS_ THROUGH | I2C_SLV4 _DONE | I2C_LOST _ARB | I2C_SLV4 _NACK | I2C_SLV3 _NACK | I2C_SLV2 _NACK | I2C_SLV1 _NACK | I2C_SLV0 _NACK |
| 37 | 55 | INT_PIN_CFG | R/W | INT_LEVEL | INT_OPEN | LATCH _INT_EN | INT_RD _CLEAR | FSYNC_ INT_LEVEL | FSYNC _INT_EN | I2C _BYPASS _EN | - |
| 38 | 56 | INT_ENABLE | R/W | - | - | - | FIFO _OFLOW _EN | I2C_MST _INT_EN | - | - | DATA _RDY_EN |
| 3A | 58 | INT_STATUS | R | - | - | - | FIFO _OFLOW _INT | I2C_MST _INT | - | - | DATA _RDY_INT |

# System Design with Sensors I - Baremetal

- Sensor Development Boards
  - Sensors
  - Gyroscope, MPU6050 Register Space

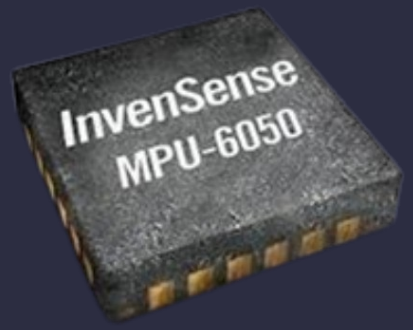




| Addr (Hex) | Addr (Dec.) | Register Name | Serial I/F | Bit7 | Bit6 | Bit5 | Bit4 | Bit3 | Bit2 | Bit1 | Bit0 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 3B | 59 | ACCEL_XOUT_H | R | ACCEL_XOUT[15:8] | | | | | | | |
| 3C | 60 | ACCEL_XOUT_L | R | ACCEL_XOUT[7:0] | | | | | | | |
| 3D | 61 | ACCEL_YOUT_H | R | ACCEL_YOUT[15:8] | | | | | | | |
| 3E | 62 | ACCEL_YOUT_L | R | ACCEL_YOUT[7:0] | | | | | | | |
| 3F | 63 | ACCEL_ZOUT_H | R | ACCEL_ZOUT[15:8] | | | | | | | |
| 40 | 64 | ACCEL_ZOUT_L | R | ACCEL_ZOUT[7:0] | | | | | | | |
| 41 | 65 | TEMP_OUT_H | R | TEMP_OUT[15:8] | | | | | | | |
| 42 | 66 | TEMP_OUT_L | R | TEMP_OUT[7:0] | | | | | | | |
| 43 | 67 | GYRO_XOUT_H | R | GYRO_XOUT[15:8] | | | | | | | |
| 44 | 68 | GYRO_XOUT_L | R | GYRO_XOUT[7:0] | | | | | | | |
| 45 | 69 | GYRO_YOUT_H | R | GYRO_YOUT[15:8] | | | | | | | |
| 46 | 70 | GYRO_YOUT_L | R | GYRO_YOUT[7:0] | | | | | | | |
| 47 | 71 | GYRO_ZOUT_H | R | GYRO_ZOUT[15:8] | | | | | | | |
| 48 | 72 | GYRO_ZOUT_L | R | GYRO_ZOUT[7:0] | | | | | | | |
| 49 | 73 | EXT_SENS_DATA_00 | R | EXT_SENS_DATA_00[7:0] | | | | | | | |
| 4A | 74 | EXT_SENS_DATA_01 | R | EXT_SENS_DATA_01[7:0] | | | | | | | |
| 4B | 75 | EXT_SENS_DATA_02 | R | EXT_SENS_DATA_02[7:0] | | | | | | | |
| 4C | 76 | EXT_SENS_DATA_03 | R | EXT_SENS_DATA_03[7:0] | | | | | | | |
| 4D | 77 | EXT_SENS_DATA_04 | R | EXT_SENS_DATA_04[7:0] | | | | | | | |
| 4E | 78 | EXT_SENS_DATA_05 | R | EXT_SENS_DATA_05[7:0] | | | | | | | |
| 4F | 79 | EXT_SENS_DATA_06 | R | EXT_SENS_DATA_06[7:0] | | | | | | | |
| 50 | 80 | EXT_SENS_DATA_07 | R | EXT_SENS_DATA_07[7:0] | | | | | | | |
| 51 | 81 | EXT_SENS_DATA_08 | R | EXT_SENS_DATA_08[7:0] | | | | | | | |
| 52 | 82 | EXT_SENS_DATA_09 | R | EXT_SENS_DATA_09[7:0] | | | | | | | |
| 53 | 83 | EXT_SENS_DATA_10 | R | EXT_SENS_DATA_10[7:0] | | | | | | | |
| 54 | 84 | EXT_SENS_DATA_11 | R | EXT_SENS_DATA_11[7:0] | | | | | | | |
| 55 | 85 | EXT_SENS_DATA_12 | R | EXT_SENS_DATA_12[7:0] | | | | | | | |
| 56 | 86 | EXT_SENS_DATA_13 | R | EXT_SENS_DATA_13[7:0] | | | | | | | |
| 57 | 87 | EXT_SENS_DATA_14 | R | EXT_SENS_DATA_14[7:0] | | | | | | | |
| 58 | 88 | EXT_SENS_DATA_15 | R | EXT_SENS_DATA_15[7:0] | | | | | | | |
| 59 | 89 | EXT_SENS_DATA_16 | R | EXT_SENS_DATA_16[7:0] | | | | | | | |
| 5A | 90 | EXT_SENS_DATA_17 | R | EXT_SENS_DATA_17[7:0] | | | | | | | |
| 5B | 91 | EXT_SENS_DATA_18 | R | EXT_SENS_DATA_18[7:0] | | | | | | | |
| 5C | 92 | EXT_SENS_DATA_19 | R | EXT_SENS_DATA_19[7:0] | | | | | | | |
| 5D | 93 | EXT_SENS_DATA_20 | R | EXT_SENS_DATA_20[7:0] | | | | | | | |
| 5E | 94 | EXT_SENS_DATA_21 | R | EXT_SENS_DATA_21[7:0] | | | | | | | |
| 5F | 95 | EXT_SENS_DATA_22 | R | EXT_SENS_DATA_22[7:0] | | | | | | | |
| 60 | 96 | EXT_SENS_DATA_23 | R | EXT_SENS_DATA_23[7:0] | | | | | | | |
| 63 | 99 | I2C_SLV0_DO | R/W | I2C_SLV0_DO[7:0] | | | | | | | |
| 64 | 100 | I2C_SLV1_DO | R/W | I2C_SLV1_DO[7:0] | | | | | | | |
| 65 | 101 | I2C_SLV2_DO | R/W | I2C_SLV2_DO[7:0] | | | | | | | |
| 66 | 102 | I2C_SLV3_DO | R/W | I2C_SLV3_DO[7:0] | | | | | | | |

# System Design with Sensors I - Baremetal

- Sensor Development Boards
  - Sensors
  - Gyroscope, MPU6050 Register Space

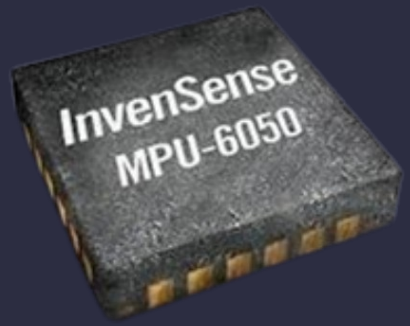




| Addr (Hex) | Addr (Dec.) | Register Name | Serial I/F | Bit7 | Bit6 | Bit5 | Bit4 | Bit3 | Bit2 | Bit1 | Bit0 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 67 | 103 | I2C_MST_DELAY_CTRL | R/W | DELAY_ES_SHADOW | - | - | I2C_SLV4_DLY_EN | I2C_SLV3_DLY_EN | I2C_SLV2_DLY_EN | I2C_SLV1_DLY_EN | I2C_SLV0_DLY_EN |
| 68 | 104 | SIGNAL_PATH_RESET | R/W | - | - | - | - | - | GYRO_RESET | ACCEL_RESET | TEMP_RESET |
| 6A | 106 | USER_CTRL | R/W | - | FIFO_EN | I2C_MST_EN | I2C_IF_DIS | - | FIFO_RESET | I2C_MST_RESET | SIG_COND_RESET |
| 6B | 107 | PWR_MGMT_1 | R/W | DEVICE_RESET | SLEEP | CYCLE | - | TEMP_DIS | CLKSEL[2:0] | | |
| 6C | 108 | PWR_MGMT_2 | R/W | LP_WAKE_CTRL[1:0] | | STBY_XA | STBY_YA | STBY_ZA | STBY_XG | STBY_YG | STBY_ZG |
| 72 | 114 | FIFO_COUNTH | R/W | FIFO_COUNT[15:8] | | | | | | | |
| 73 | 115 | FIFO_COUNTL | R/W | FIFO_COUNT[7:0] | | | | | | | |
| 74 | 116 | FIFO_R_W | R/W | FIFO_DATA[7:0] | | | | | | | |
| 75 | 117 | WHO_AM_I | R | - | WHO_AM_I[6:1] | | | | | | - |

# System Design with Sensors I - Baremetal

- Sensor Development Boards
  - Sensors
  - Gyroscope, MPU6050 Register Space
  - Disable sleep mode
  - Read Registers 59 to 72 for Gyro and Acc Data



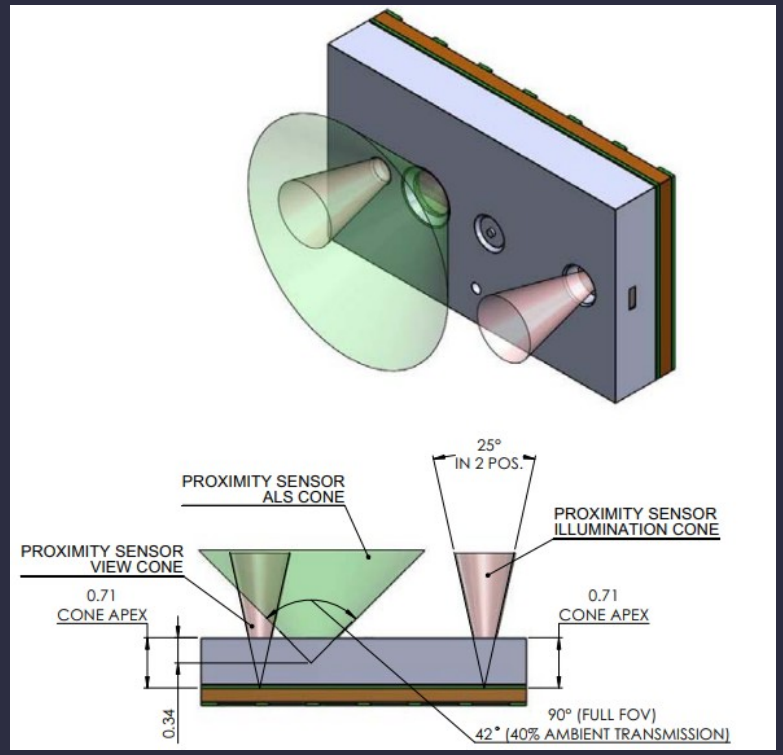

# System Design with Sensors I - Baremetal

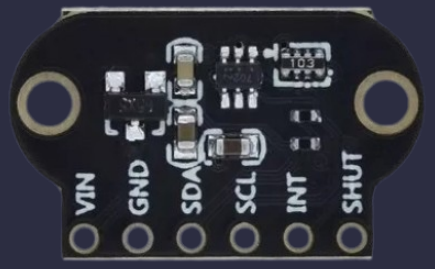
- Sensor Development Boards
  - Sensors
  - Laser Distance Measurement, TOF050C
  - ToF distance sensor module based on the VL6180X system. It uses FlightSense™ technology that allows you to measure the absolute distance regardless of the color and surface of the detected object.
  - Range: 2 to 50 cm
  - Dead zone: 0 to 2 cm
  - Interface: I2C
  - I2C address: 0x29
  - Viewing Angle (FOV): 25°
  - Power supply: 3 to 5 V

Details:
https://www.st.com/en/imaging-and-photonics-solutions/vl6180x.html

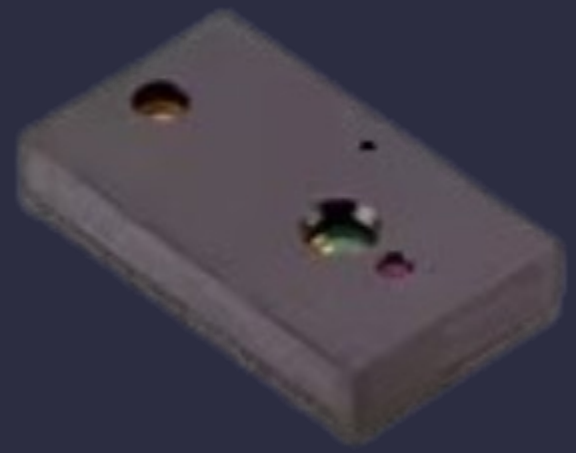

# System Design with Sensors I - Baremetal

- Sensor Development Boards
  - Sensors
  - Laser Distance Measurement, TOF050C



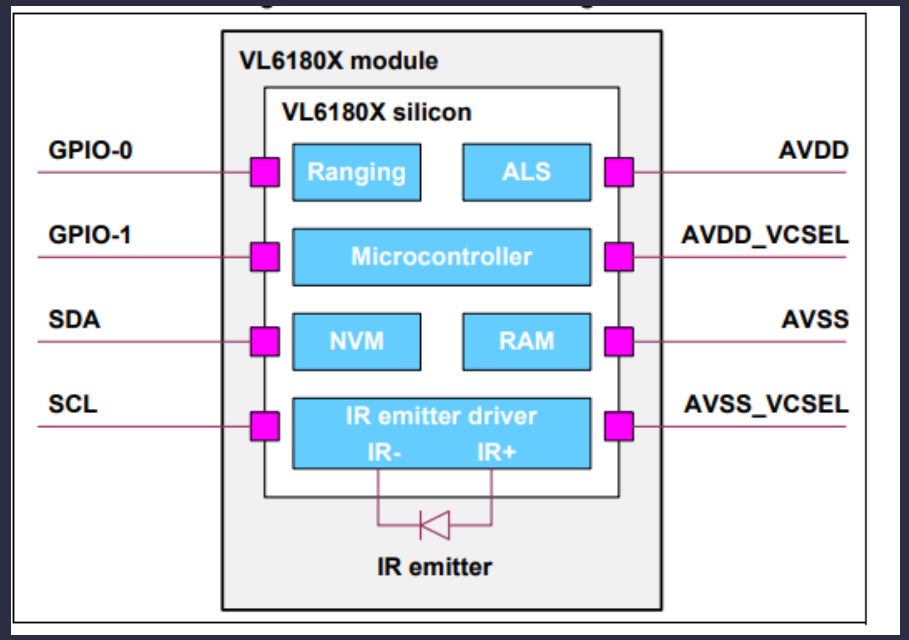





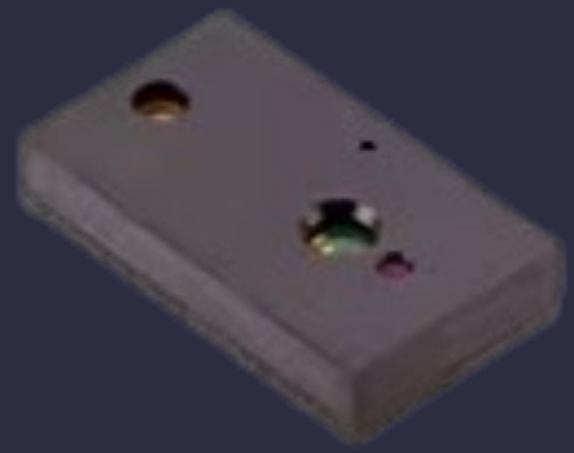


# System Design with Sensors I - Baremetal

- Sensor Development Boards
  - Sensors
  - Laser Distance Measurement, TOF050C, I/Os







# System Design with Sensors I - Baremetal

- Sensor Development Boards
  - Sensors
  - Laser Distance Measurement, TOF050C, Register Map


| Offset | Register name |
|---|---|
| 0x000 | IDENTIFICATION__MODEL_ID |
| 0x001 | IDENTIFICATION__MODEL_REV_MAJOR |
| 0x002 | IDENTIFICATION__MODEL_REV_MINOR |
| 0x003 | IDENTIFICATION__MODULE_REV_MAJOR |
| 0x004 | IDENTIFICATION__MODULE_REV_MINOR |
| 0x006 | IDENTIFICATION__DATE_HI |
| 0x007 | IDENTIFICATION__DATE_LO |
| 0x008:0x009 | IDENTIFICATION__TIME |
| 0x010 | SYSTEM__MODE_GPIO0 |
| 0x011 | SYSTEM__MODE_GPIO1 |
| 0x012 | SYSTEM__HISTORY_CTRL |
| 0x014 | SYSTEM__INTERRUPT_CONFIG_GPIO |
| 0x015 | SYSTEM__INTERRUPT_CLEAR |
| 0x016 | SYSTEM__FRESH_OUT_OF_RESET |
| 0x017 | SYSTEM__GROUPED_PARAMETER_HOLD |
| 0x018 | SYSRANGE__START |
| 0x019 | SYSRANGE__THRESH_HIGH |
| 0x01A | SYSRANGE__THRESH_LOW |
| 0x01B | SYSRANGE__INTERMEASUREMENT_PERIOD |
| 0x01C | SYSRANGE__MAX_CONVERGENCE_TIME |
| 0x01E | SYSRANGE__CROSSTALK_COMPENSATION_RATE |
| 0x021 | SYSRANGE__CROSSTALK_VALID_HEIGHT |
| 0x022 | SYSRANGE__EARLY_CONVERGENCE_ESTIMATE |
| 0x024 | SYSRANGE__PART_TO_PART_RANGE_OFFSET |
| 0x025 | SYSRANGE__RANGE_IGNORE_VALID_HEIGHT |
| 0x026 | SYSRANGE__RANGE_IGNORE_THRESHOLD |
| 0x02C | SYSRANGE__MAX_AMBIENT_LEVEL_MULT |
| 0x02D | SYSRANGE__RANGE_CHECK_ENABLES |
| 0x02E | SYSRANGE__VHV_RECALIBRATE |
| 0x031 | SYSRANGE__VHV_REPEAT_RATE |
| 0x038 | SYSALS__START |
| 0x03A | SYSALS__THRESH_HIGH |
| 0x03C | SYSALS__THRESH_LOW |

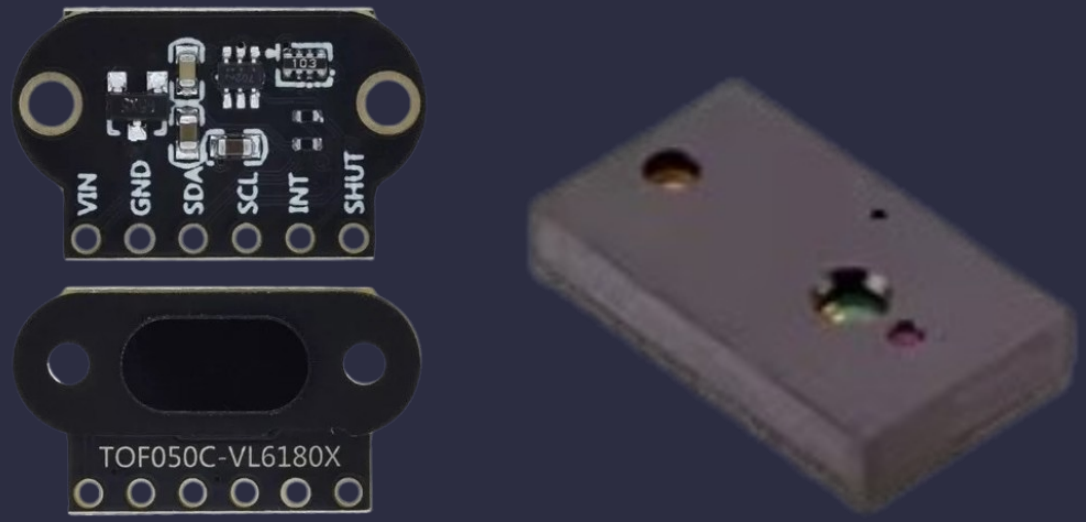
# System Design with Sensors I - Baremetal

- Sensor Development Boards
  - Sensors
  - Laser Distance Measurement, TOF050C, Register Map


| Offset | Register name |
|---|---|
| 0x03E | SYSALS__INTERMEASUREMENT_PERIOD |
| 0x03F | SYSALS__ANALOGUE_GAIN |
| 0x040 | SYSALS__INTEGRATION_PERIOD |
| 0x04D | RESULT__RANGE_STATUS |
| 0x04E | RESULT__ALS_STATUS |
| 0x04F | RESULT__INTERRUPT_STATUS_GPIO |
| 0x050 | RESULT__ALS_VAL |
| 0x052:0x060 (0x2) | RESULT__HISTORY_BUFFER_x |
| 0x062 | RESULT__RANGE_VAL |
| 0x064 | RESULT__RANGE_RAW |
| 0x066 | RESULT__RANGE_RETURN_RATE |
| 0x068 | RESULT__RANGE_REFERENCE_RATE |
| 0x06C | RESULT__RANGE_RETURN_SIGNAL_COUNT |
| 0x070 | RESULT__RANGE_REFERENCE_SIGNAL_COUNT |
| 0x074 | RESULT__RANGE_RETURN_AMB_COUNT |
| 0x078 | RESULT__RANGE_REFERENCE_AMB_COUNT |
| 0x07C | RESULT__RANGE_RETURN_CONV_TIME |
| 0x080 | RESULT__RANGE_REFERENCE_CONV_TIME |
| 0x10A | READOUT__AVERAGING_SAMPLE_PERIOD |
| 0x119 | FIRMWARE__BOOTUP |
| 0x120 | FIRMWARE__RESULT_SCALER |
| 0x212 | I2C_SLAVE__DEVICE_ADDRESS |
| 0x2A3 | INTERLEAVED_MODE__ENABLE |

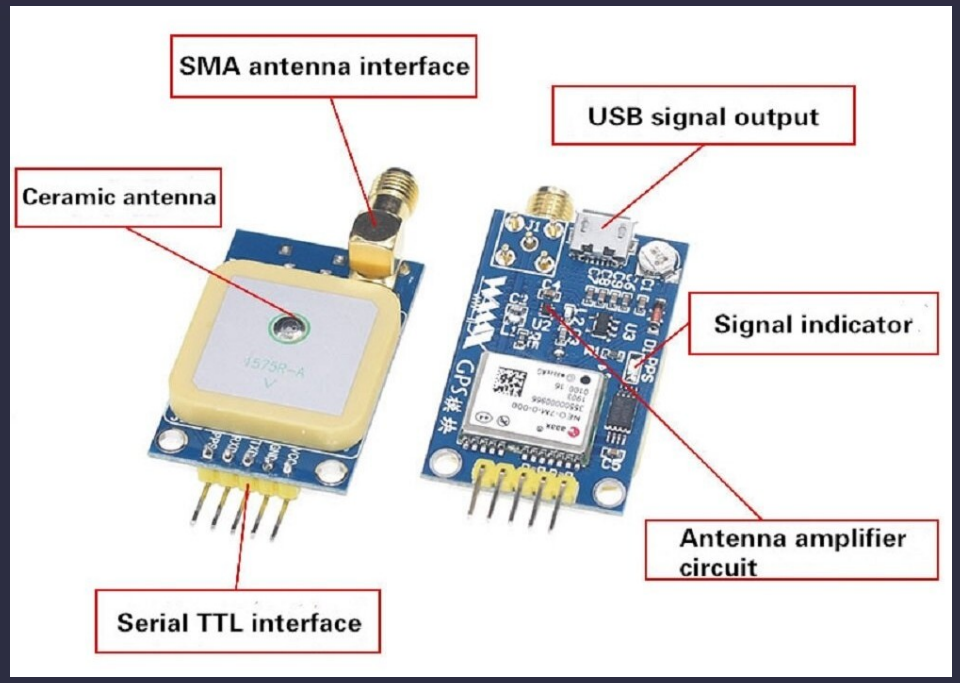
# System Design with Sensors I - Baremetal

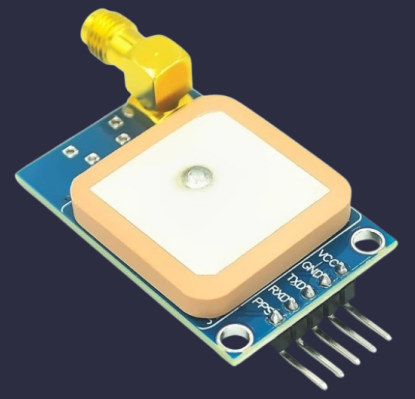
- Sensor Development Boards
  - Sensors
  - Laser Distance Measurement, TOF050C
  - Measurement
  - Write SYSRANGE_START (Addr 0x0) to 1
  - Wait RESULT_INTERRUPT_STATUS Register 0x4F
  - Read RESULT_RANGE_VAL Register 0x62



# System Design with Sensors I - Baremetal

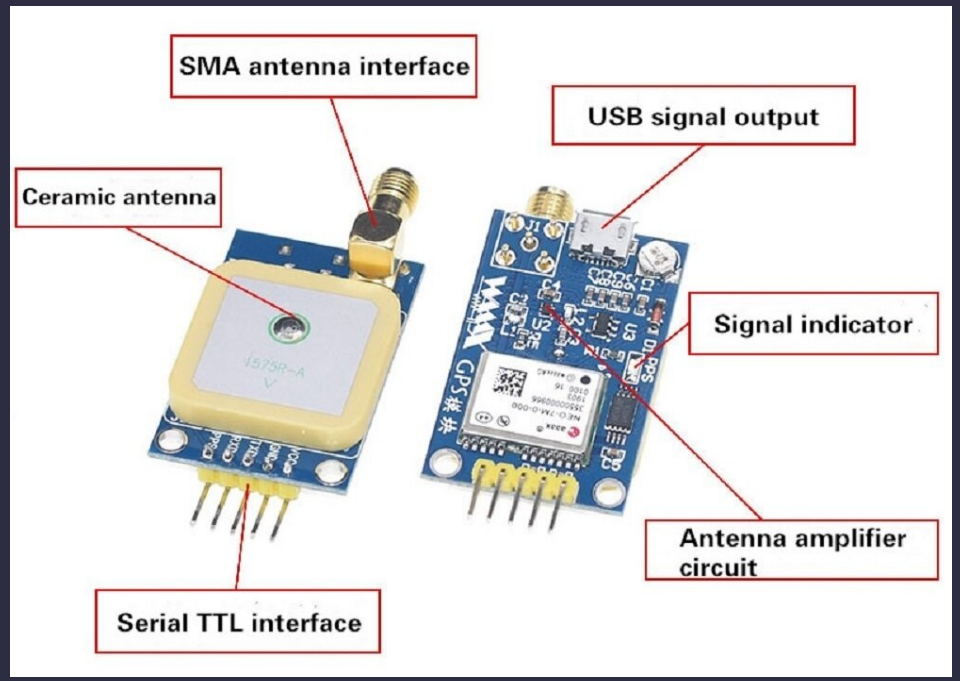
- Sensor Development Boards
  - Sensors
  - GPS, NEO-7M
  - GPS Satellite Positioning Module
  - UART Interface
  - NMEA (National Marine Electronics Association) 0183
  - Details:
  - https://content.u-blox.com/sites/default/files/products/documents/NEO-7_DataSheet_%28UBX-13003830%29.pdf

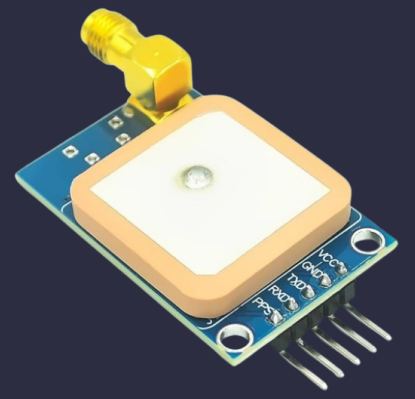


# System Design with Sensors I - Baremetal

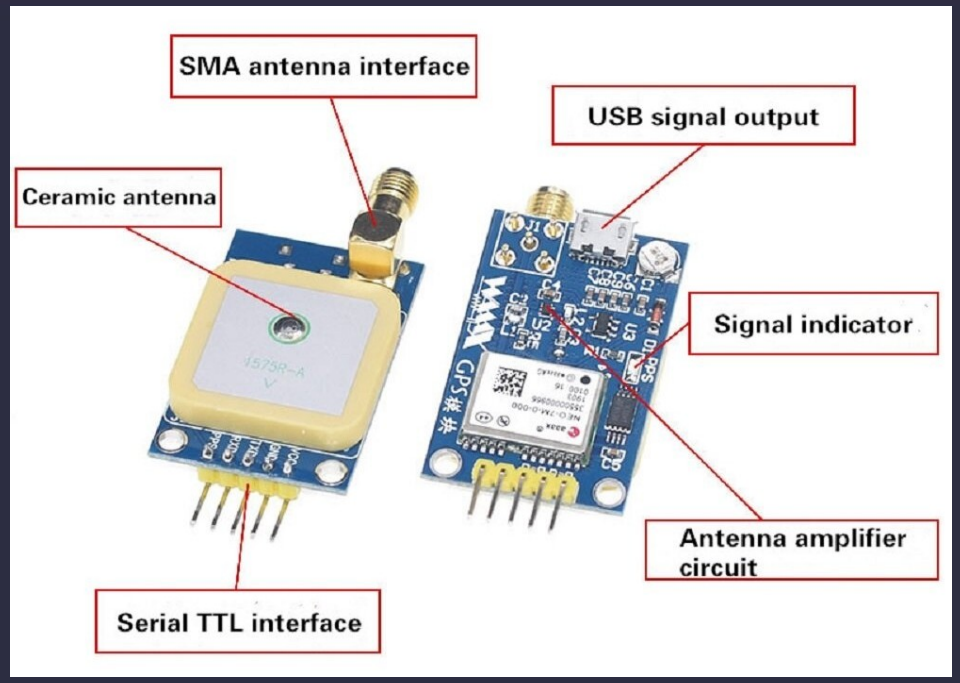
- Sensor Development Boards
  - Sensors
  - GPS, NEO-7M
  - GPRMC (Recommended Minimum Navigation Information):Provides essential data including time, date, latitude, longitude, speed, and course over ground.
  - GPGGA (Global Positioning System Fix Data):Contains detailed fix information such as latitude, longitude, altitude, fix quality, and the number of satellites used.
  - GPGSA (GPS DOP and Active Satellites):Indicates which satellites are being used for the fix and provides dilution of precision (DOP) values for positioning accuracy.
  - GPGSV (GPS Satellites in View):Lists all satellites in view along with details like satellite ID, elevation, azimuth, and signal-to-noise ratio.
  - GPVTG (Track Made Good and Ground Speed):Reports the ground track (direction) and speed over ground.
  - GPGLL (Geographic Position – Latitude/Longitude):Outputs the current position (latitude and longitude) along with a status indicator to show if the data is valid.



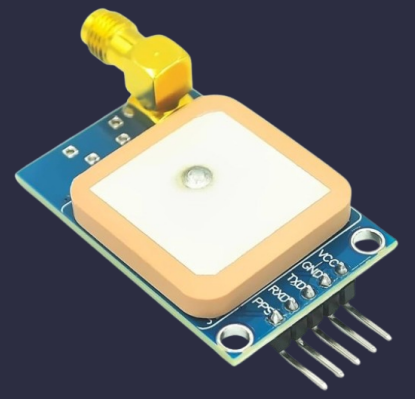
# System Design with Sensors I - Baremetal

- Sensor Development Boards
  - Sensors
  - GPS, NEO-7M
  - Sample NMEA Message



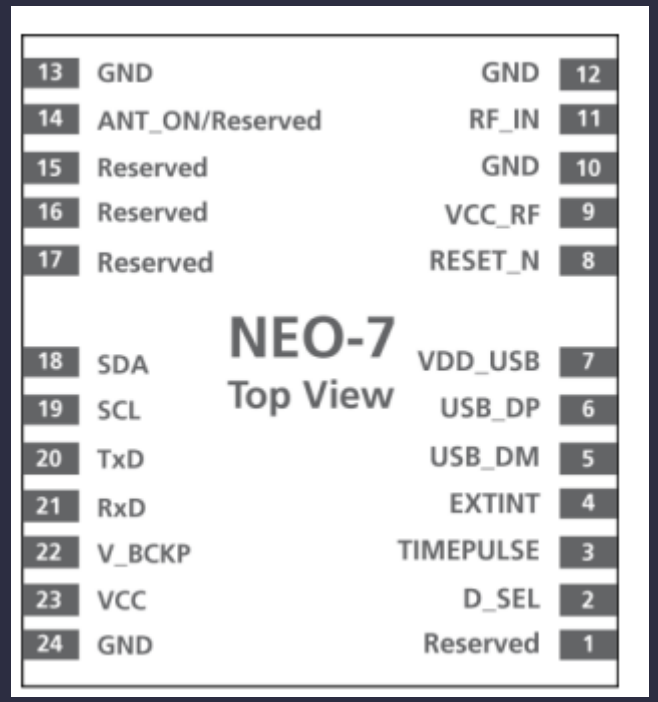

Text Console

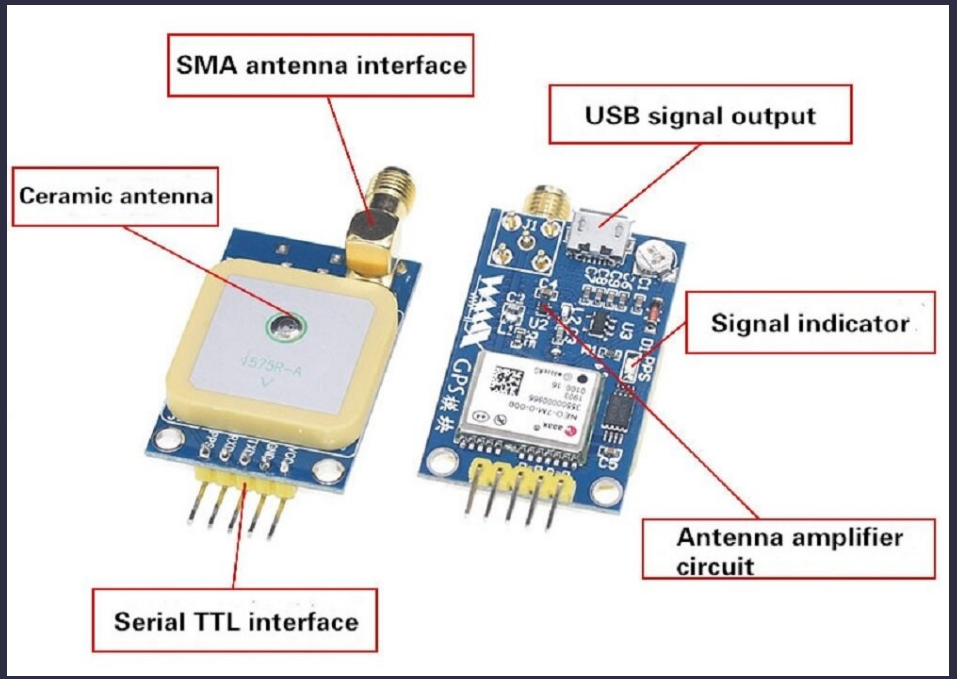
```
$GBGSV,3,3,11,27,58,131,33,20,16,217,28,32,72,199,34,8*4D
$GBGSV,1,1,04,05,38,141,34,13,22,059,27,02,22,114,35,09,14,107,28,B*07
$GAGSV,2,1,05,33,60,068,32,10,26,299,24,12,49,312,30,19,44,156,27,1*79
$GAGSV,2,2,05,26,16,099,29,1*48
$GAGSV,2,1,05,33,60,068,33,10,26,299,26,12,49,312,32,19,44,156,28,2*74
$GAGSV,2,2,05,26,16,099,25,2*47
$GAGSV,1,1,04,33,60,068,34,12,49,312,36,19,44,156,30,31,12,223,25,7*7F
$GNGGA,115144.00,3953.37121850,N,03243.10270985,E,2,06,2.2,955.0549,M,37.3246,M,02,0001*77
$GNZDA,115144.00,12,06,2024,,*7D
$GNGSA,M,3,08,21,27,,,,,,,,,6.9,2.2,6.6,1*3C
$GNGSA,M,3,65,72,88,,,,,,,,,6.9,2.2,6.6,2*37
$GNRMC,115144.00,A,3953.37121850,N,03243.10270985,E,1.197,242.8,120624,4.5,E,D,V*51
$GNGST,115144.00,1.07,24.68,8.92,59.1708,11.701,17.158,30.796*75
$GNVTG,242.808,T,238.325,M,1.19680,N,2.21647,K,A*37
$GPGSV,2,1,05,08,61,274,38,10,56,040,33,21,37,305,35,27,59,192,34,1*62
$GPGSV,2,2,05,23,22,053,29,1*5D
$GPGSV,1,1,02,10,56,040,26,21,37,305,33,4*60
$GPGSV,1,1,04,08,61,274,34,10,56,040,30,27,59,192,33,23,22,053,25,8*66
$GLGSV,1,1,03,65,63,195,35,88,55,338,35,72,51,038,34,1*45
$GLGSV,1,1,03,65,63,195,28,88,55,338,33,72,51,038,29,3*41
$GBGSV,2,1,07,30,65,309,34,41,46,048,29,60,24,119,24,13,22,059,27,1*78
$GBGSV,2,2,07,27,58,131,32,20,16,217,25,32,72,199,33,1*48
```

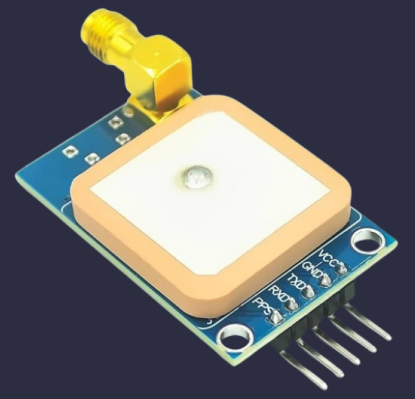


# System Design with Sensors I - Baremetal

- Sensor Development Boards
  - Sensors
  - GPS, NEO-7M, I/Os

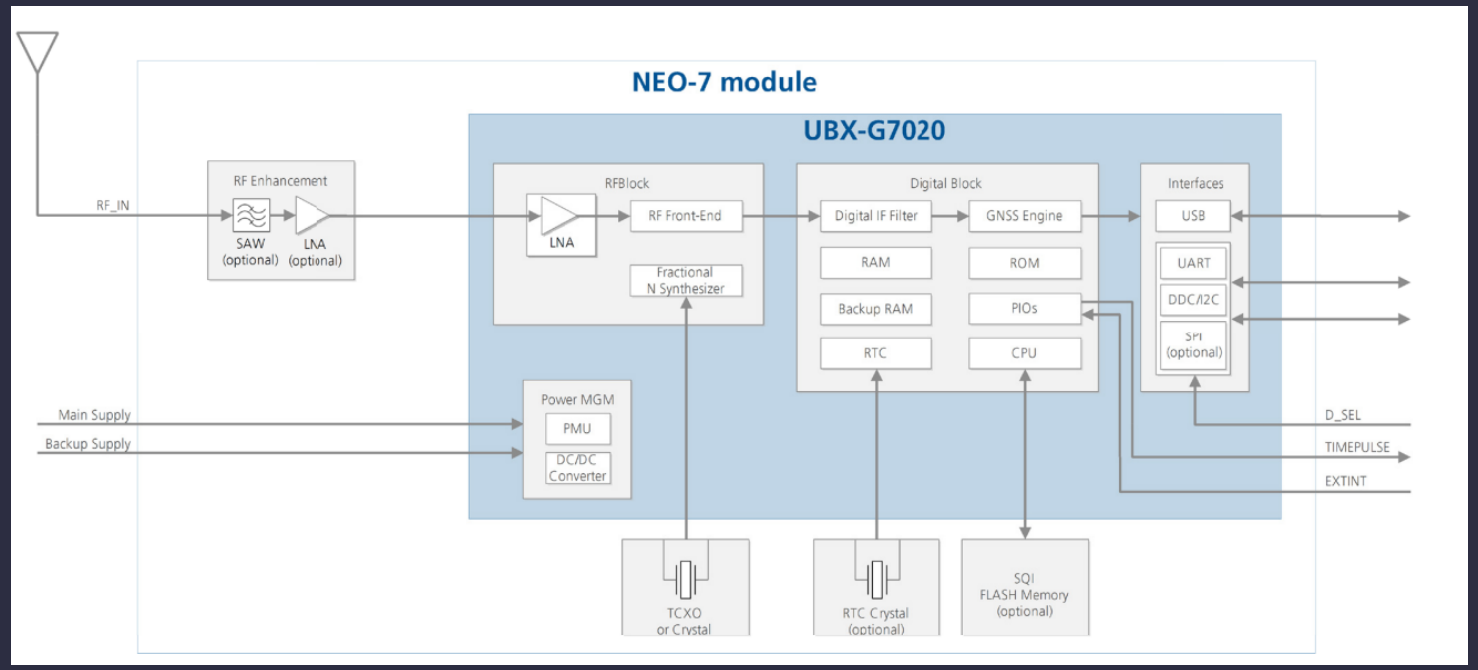


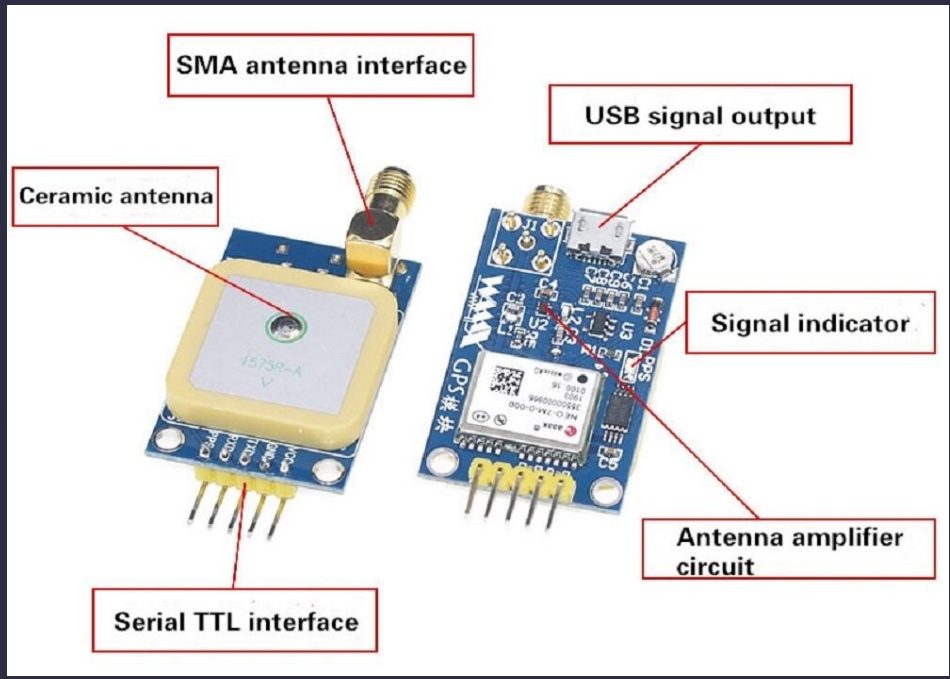



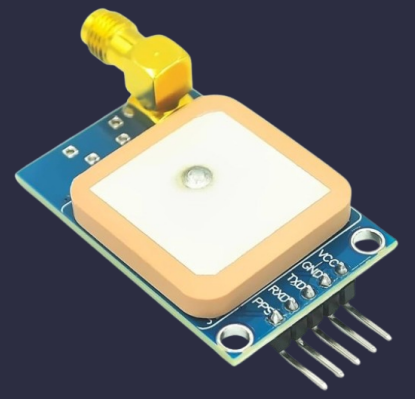



# System Design with Sensors I - Baremetal

- Sensor Development Boards
  - Sensors
  - GPS, NEO-7M, Block Diagram

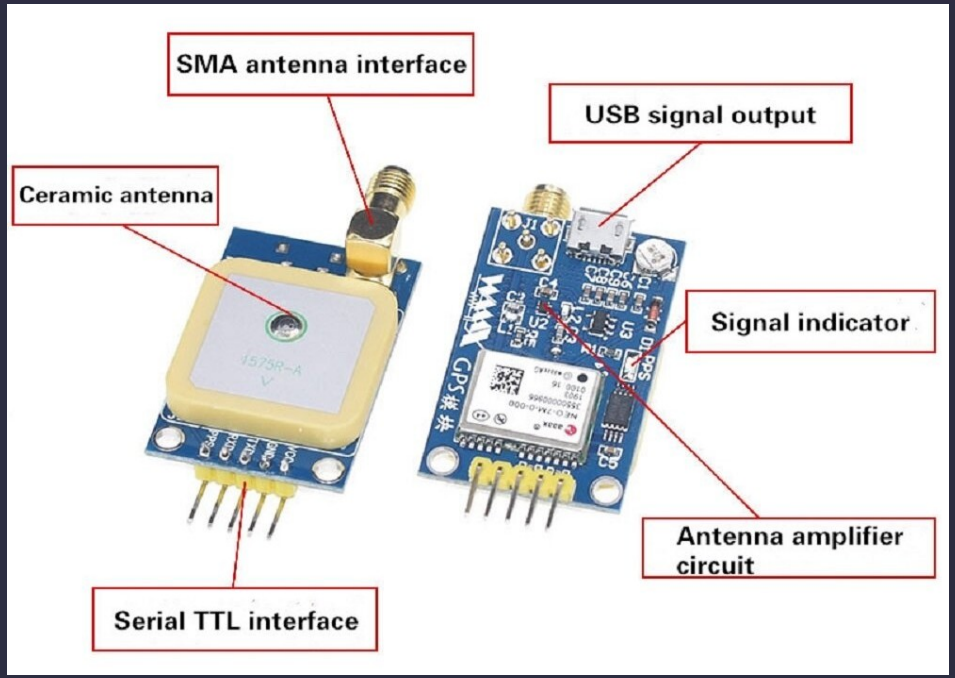


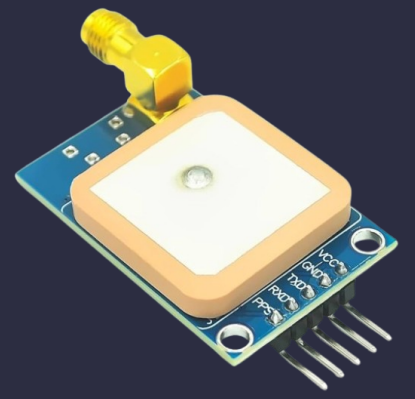



# System Design with Sensors I - Baremetal

- Sensor Development Boards
  - Sensors
  - GPS, NEO-7M, Example Settings
  - Baud Rate Change: Can change the default baud rate (e.g., from 9600 to 115200) using the UBX-CFG-PRT command.
  - Update Rate Adjustment: Configure the measurement rate (e.g., setting the module to output data at 1 Hz or 5 Hz) with the UBX-CFG-RATE command.
  - NMEA Sentence Control: Enable or disable specific NMEA sentences (like turning off the GPGSV sentence) using UBX-CFG-MSG or similar commands to reduce data load.
  - Dynamic Model Setting: Adjust the dynamic model (e.g., for pedestrian, automotive, or airborne use) via the UBX-CFG-NAV5 command.



# System Design with Sensors I - Baremetal

- Sensor Development Boards
  - Sensors

  - RF Transceiver, Dorji DRF1278DM

  - Semtech SX1278 IC
  - Voltage: 3,4V-5,5V
  - Communication: UART
  - Maximum Power: 20dBm - 100mW
  - Receiver Sensivity 300bps: -138dBm
  - Data Rate: 1,2Kbps - 9,6Kbps - 57,6Kbps
  - Frequency 420MHz - 450MHz
  - Rf Wakeup Time: 2sec - 10sec

  - Details:
  https://www.semtech.com/products/wireless-rf/lora-connect/sx1278

# System Design with Sensors I - Baremetal

- Sensor Development Boards
  - Sensors
  - RF Transceiver, Dorji DRF1278DM, Block Diagram

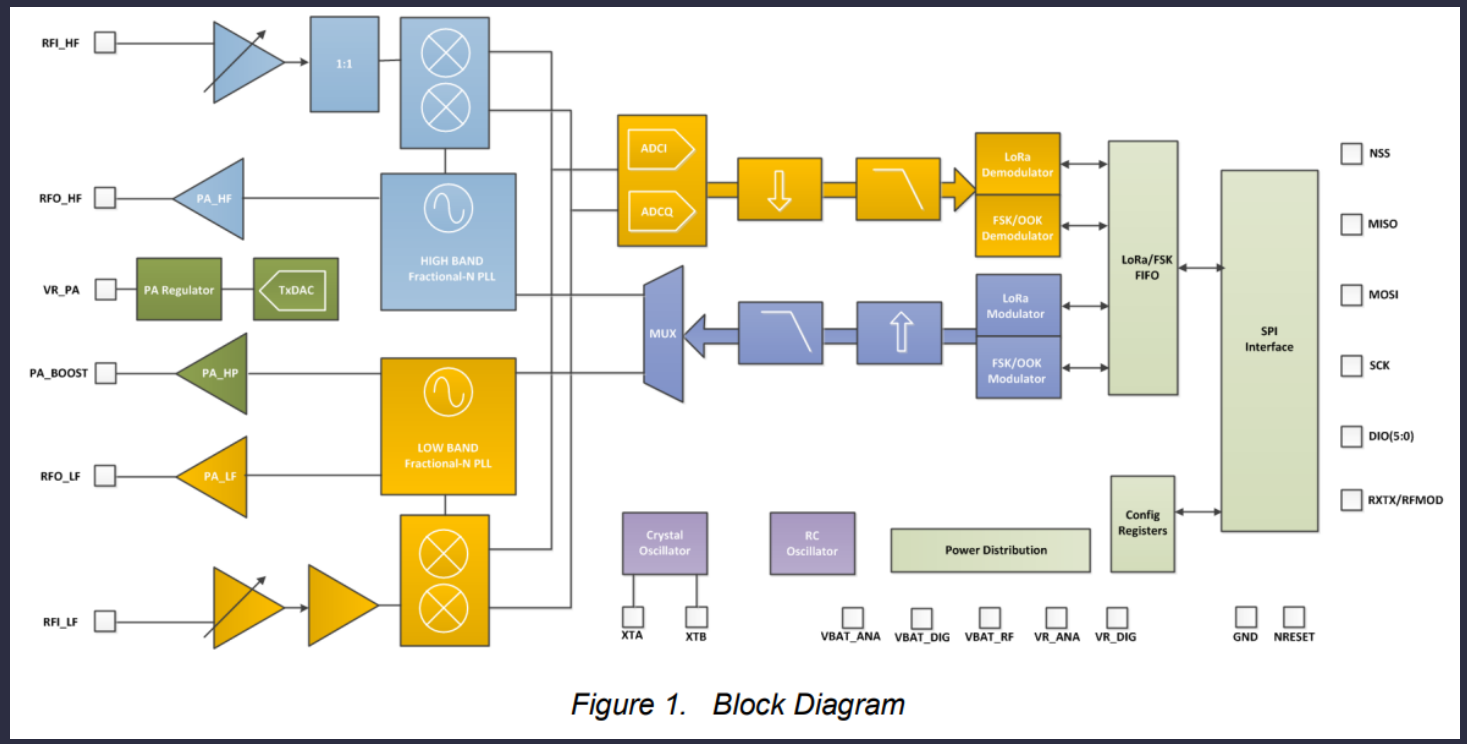
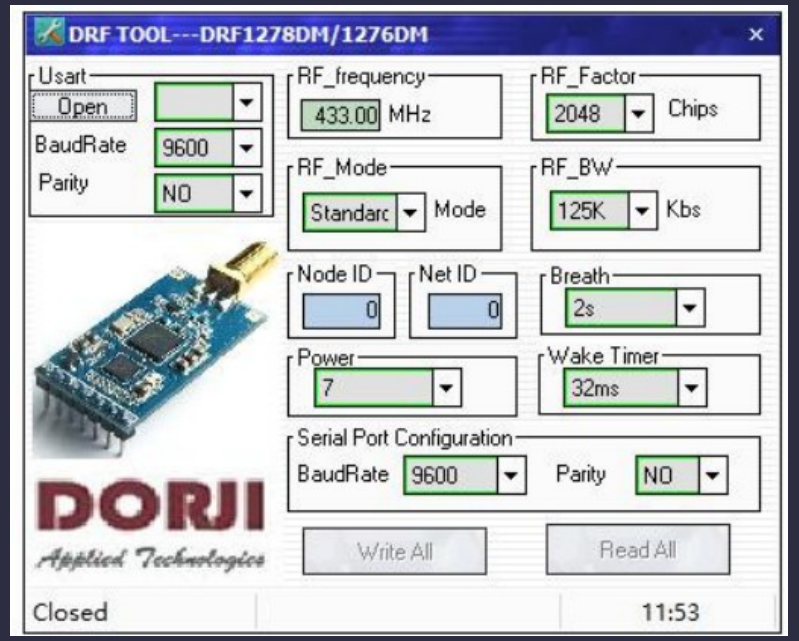



*Figure 1. Block Diagram*

# System Design with Sensors I - Baremetal

- Sensor Development Boards
  - Sensors
  - RF Transceiver, Dorji DRF1278DM, Block Diagram





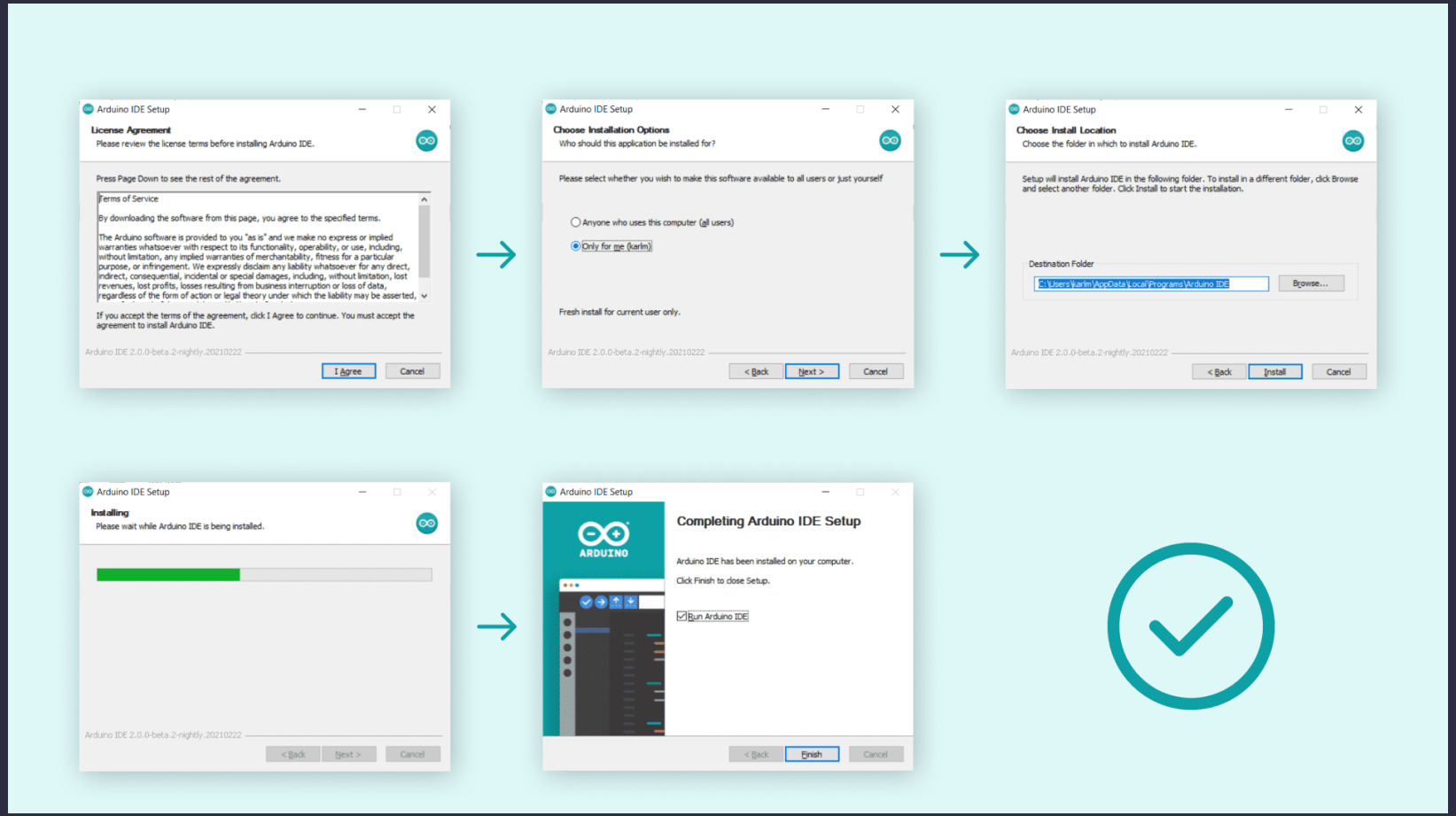
- Details:
https://www.dorji.com/docs/data/DRF1278DM.pdf

# System Design with Sensors I - Baremetal

- Ardunio IDE

Download and Install

https://www.arduino.cc/en/software#experimental-software

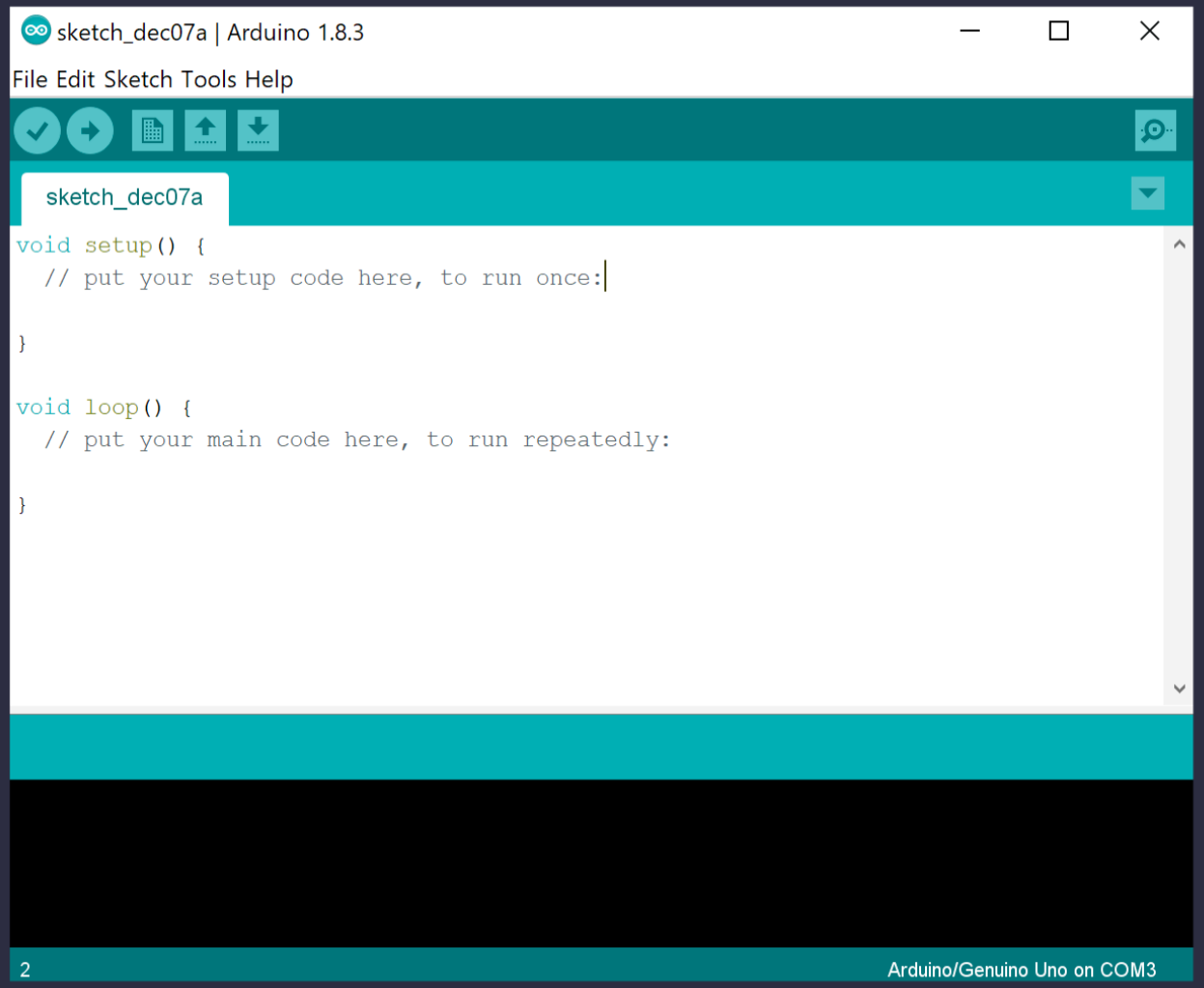


# System Design with Sensors I - Baremetal

- Ardunio IDE

There are two main tools when uploading a sketch to a board: verify and upload.

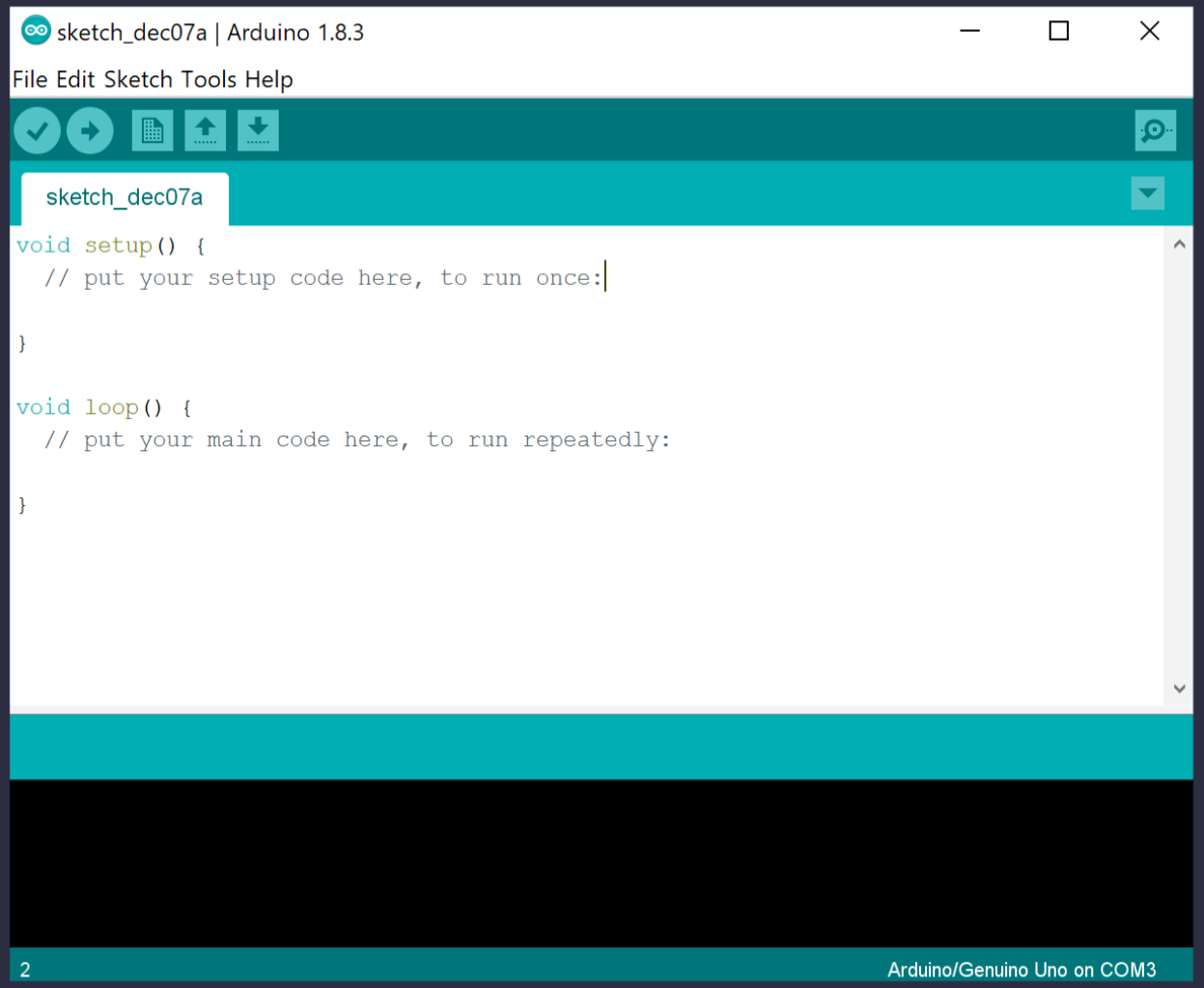
- The verify tool simply goes through your sketch, checks for errors and compiles it.
- The upload tool does the same, but when it finishes compiling the code, it also uploads it to the board



# System Design with Sensors I - Baremetal

- Ardunio IDE

A good practice is to use the verifying tool before attempting to upload anything. This is a quick way of spotting any errors in your code, so you can fix them before actually uploading the code.



# System Design with Sensors I - Baremetal

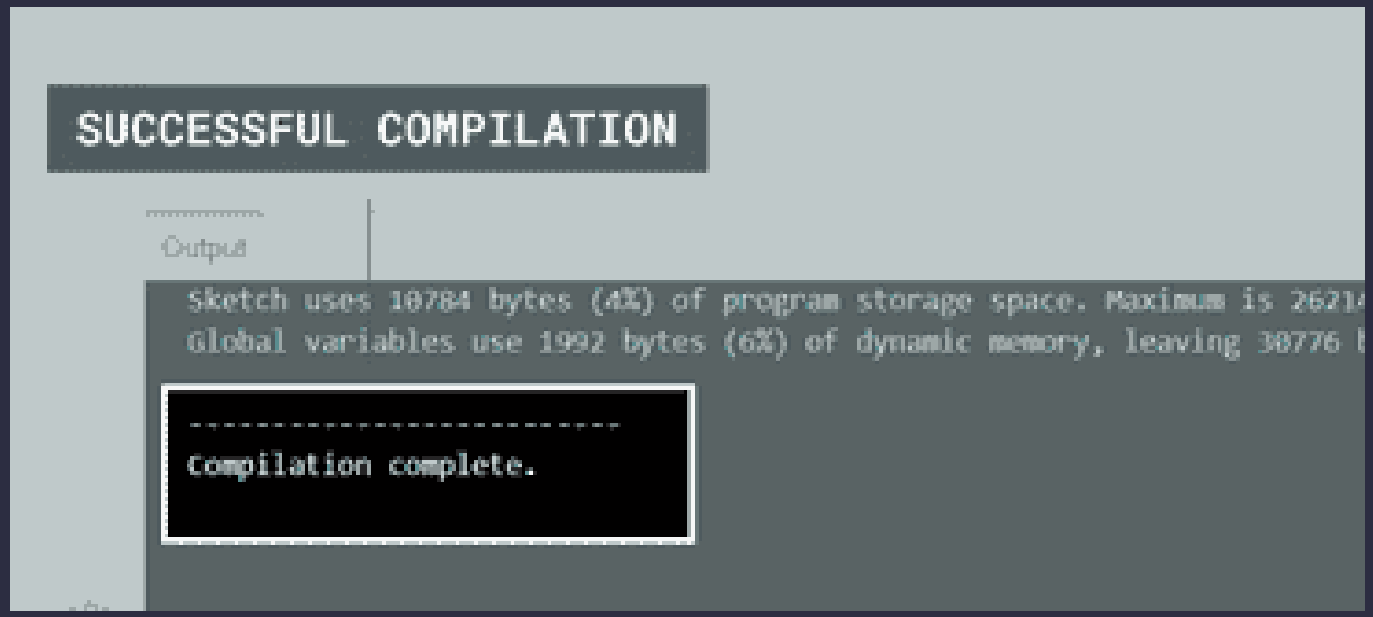
- Ardunio IDE

At the very left, there is a checkmark and an arrow pointing right. The checkmark is used to verify, and the arrow is used to upload.

# System Design with Sensors I - Baremetal

- Ardunio IDE

Click on the verify tool (checkmark).

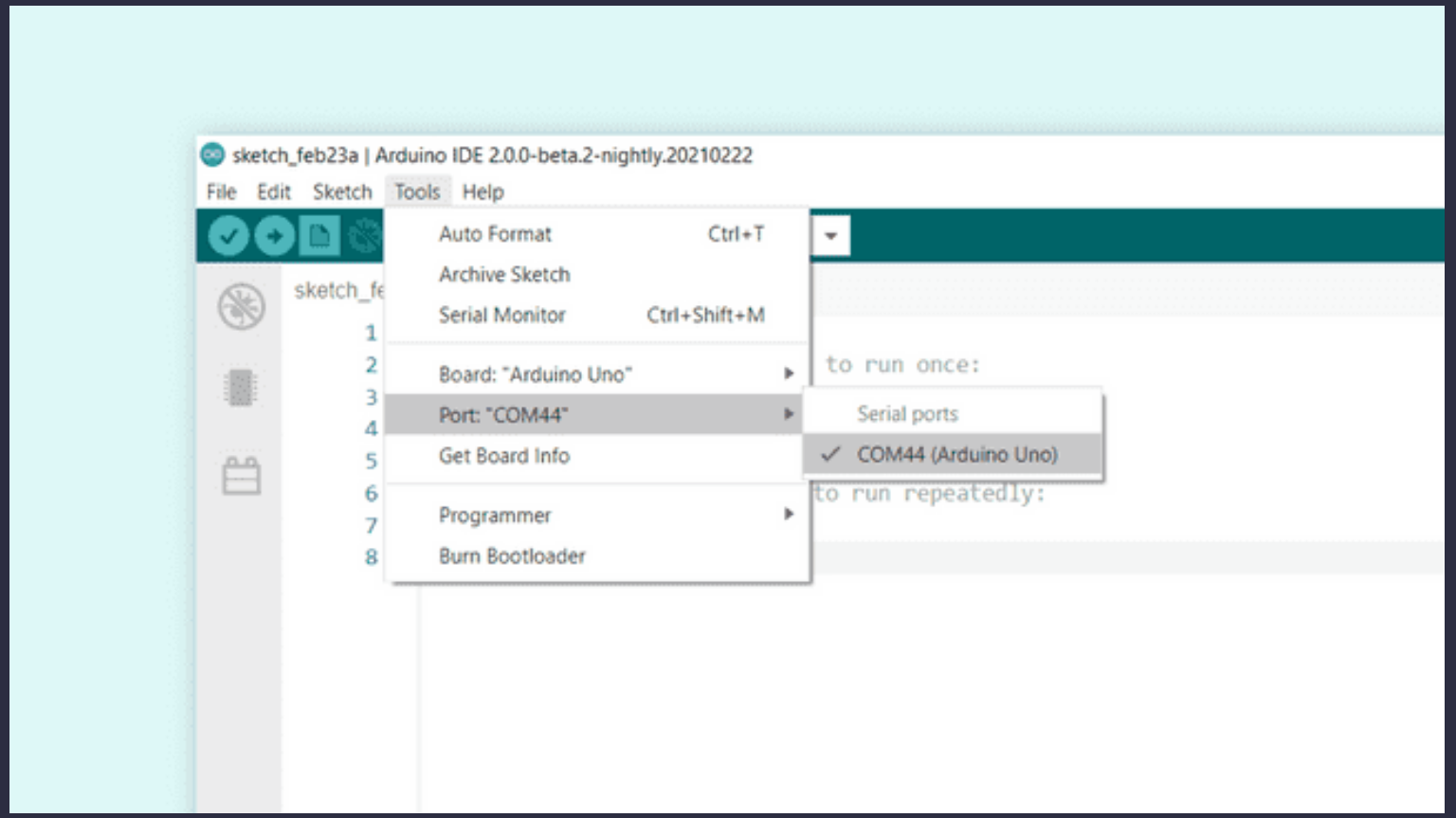


# System Design with Sensors I - Baremetal

- Ardunio IDE

Select the board that we are using

Tools > Port > {Board}

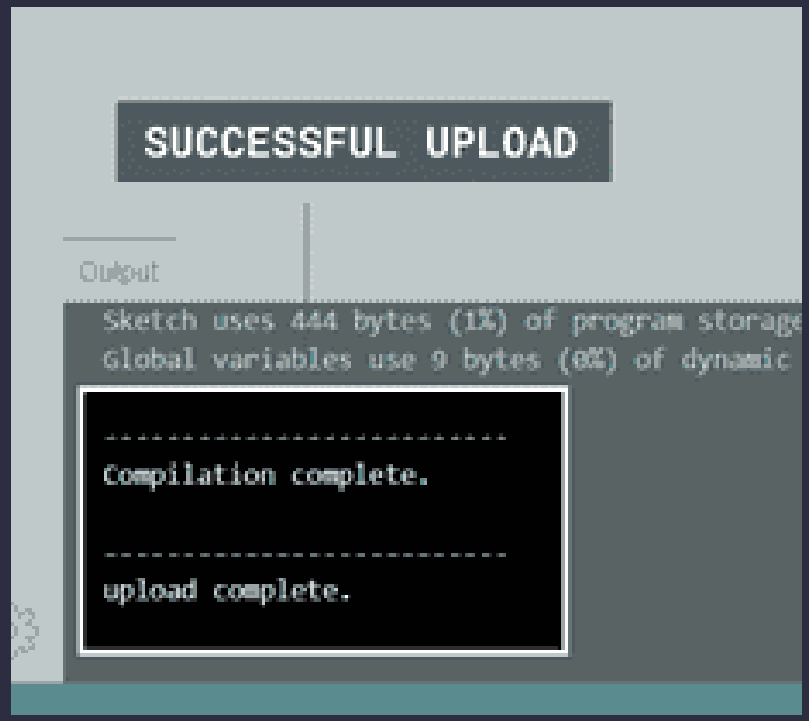


# System Design with Sensors I - Baremetal

- Ardunio IDE

Click on the upload button, and it will start uploading the sketch to the board

When it is finished, it will notify you in the console log.

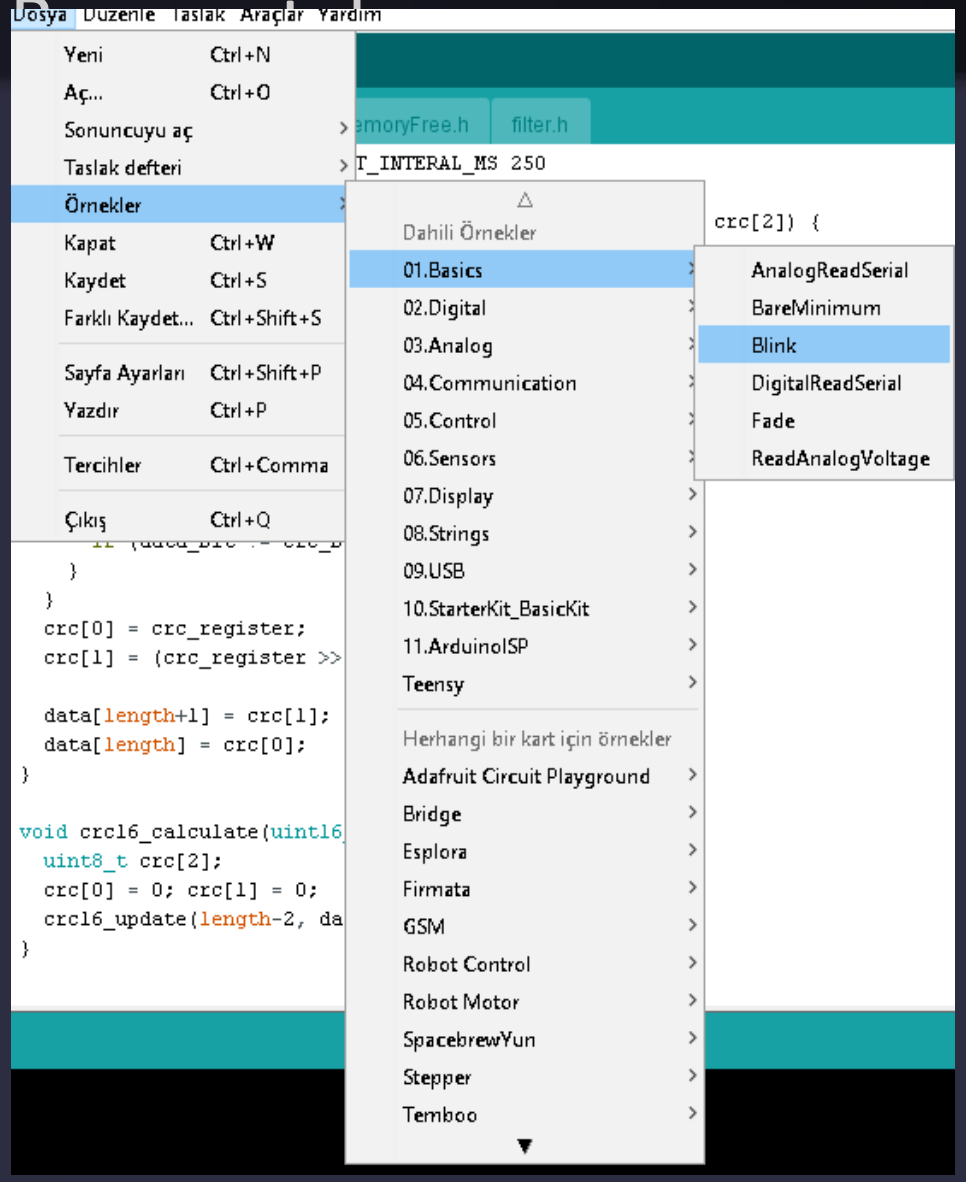


# System Design with Sensors I - Part I

- Ardunio IDE

Examples under

File -> Examples ->

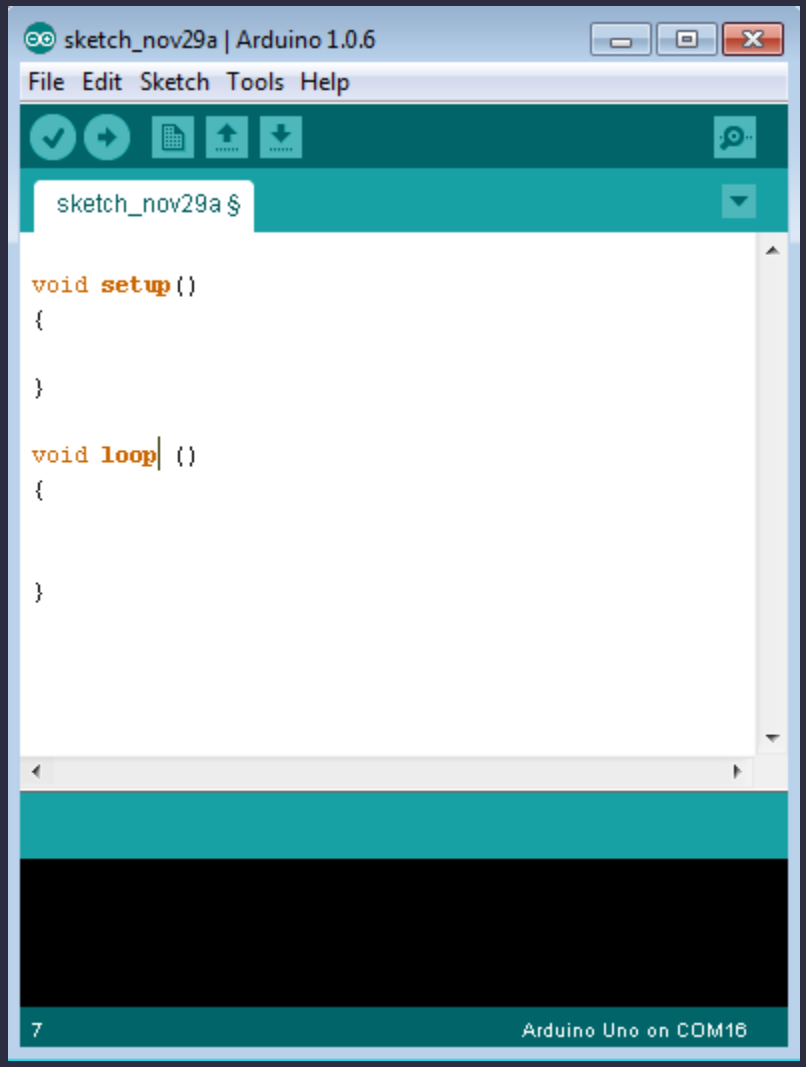


# System Design with Sensors I - Baremetal

- Ardunio IDE

Software structure consist of two main functions

- Setup( ) function
- Loop( ) function



# System Design with Sensors I - Baremetal

- Ardunio IDE

```
void setup ( ) {


}
```

PURPOSE – The setup() function is called when a sketch starts. Use it to initialize the variables, pin modes, start using libraries, etc. The setup function will only run once, after each power up or reset of the Arduino board.

# System Design with Sensors I - Baremetal

- Ardunio IDE

```
void loop ( ) {

}
```

PURPOSE – After creating a setup() function, which initializes and sets the initial values, the loop() function does precisely what its name suggests, and loops consecutively, allowing your program to change and respond. Use it to actively control the Arduino board.

# System Design with Sensors I - Baremetal

- Ardunio IDE

Data types

| **void** | **Boolean** | **char** | **Unsigned char** | **byte** | **int** | **Unsigned int** | **word** |
|---|---|---|---|---|---|---|---|
| long | Unsigned long | short | float | double | array | String-char array | String-object |

# System Design with Sensors I - Baremetal

- Ardunio IDE

The pins on the Arduino board can be configured as either inputs or outputs.

pinMode() function can set a pin to input or output

pinMode(3,INPUT) ; // set pin to input without using built in pull up resistor

# System Design with Sensors I - Baremetal

- Ardunio IDE

Arduino provides four different time manipulation functions

| | Function & Description |
|---|---|
| 1 | delay () function<br>The way the **delay()** function works is pretty simple. It accepts a single integer (or number) argument. This number represents the time (measured in milliseconds). |
| 2 | delayMicroseconds () function<br>The **delayMicroseconds()** function accepts a single integer (or number) argument. There are a thousand microseconds in a millisecond, and a million microseconds in a second. |
| 3 | millis () function<br>This function is used to return the number of milliseconds at the time, the Arduino board begins running the current program. |
| 4 | micros () function<br>The micros() function returns the number of microseconds from the time, the Arduino board begins running the current program. This number overflows i.e. goes back to zero after approximately 70 minutes. |

# System Design with Sensors I - Baremetal

- Ardunio IDE

digitalWrite() Function

The digitalWrite() function is used to write a HIGH or a LOW value to a digital pin. If the pin has been configured as an OUTPUT with pinMode()

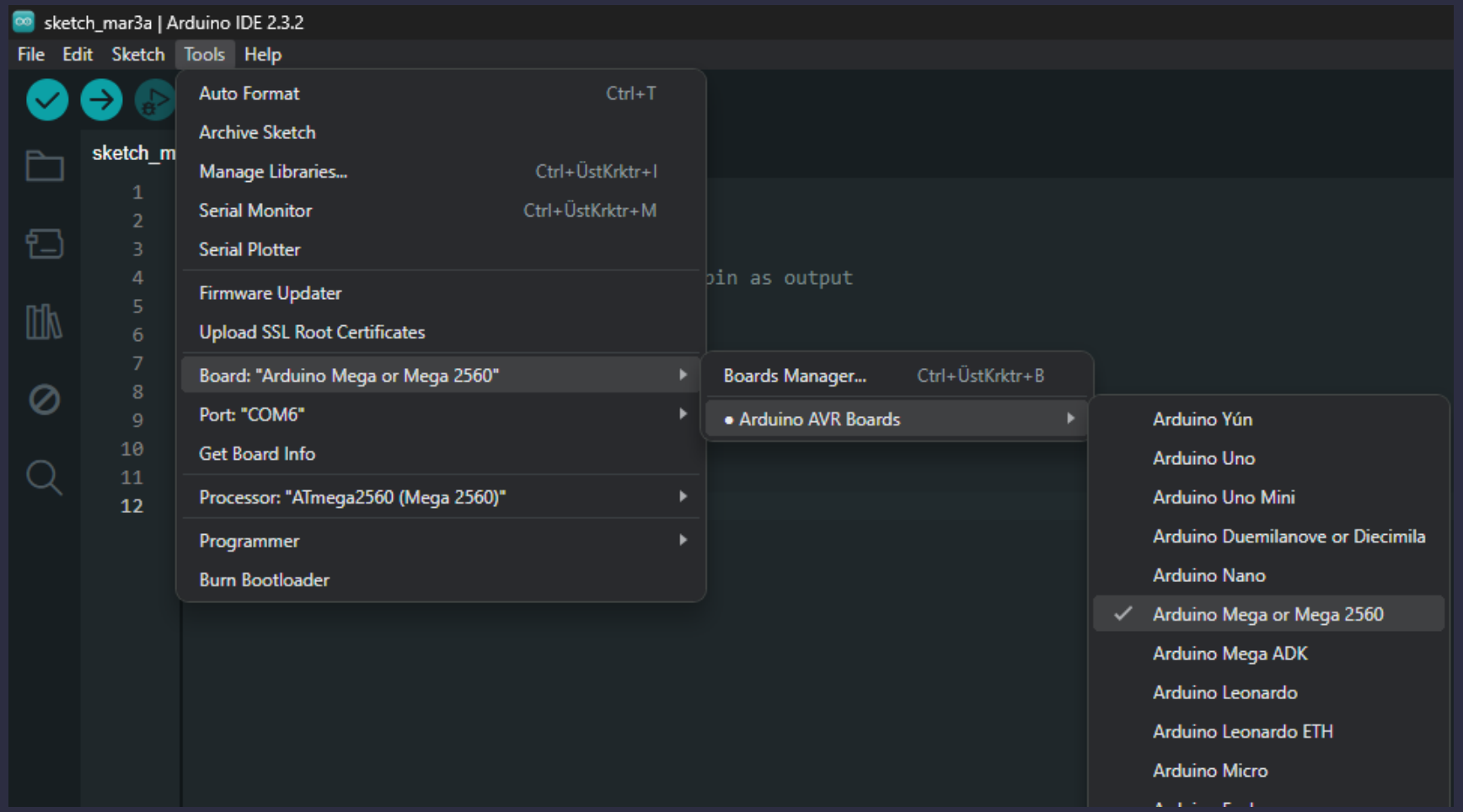
its voltage will be set to the corresponding value: 5V (or 3.3V on 3.3V boards) for HIGH, 0V (ground) for LOW.

# System Design with Sensors I - Baremetal

- Ardunio IDE

Compilation

Select Board



# System Design with Sensors I - Baremetal

- Ardunio IDE

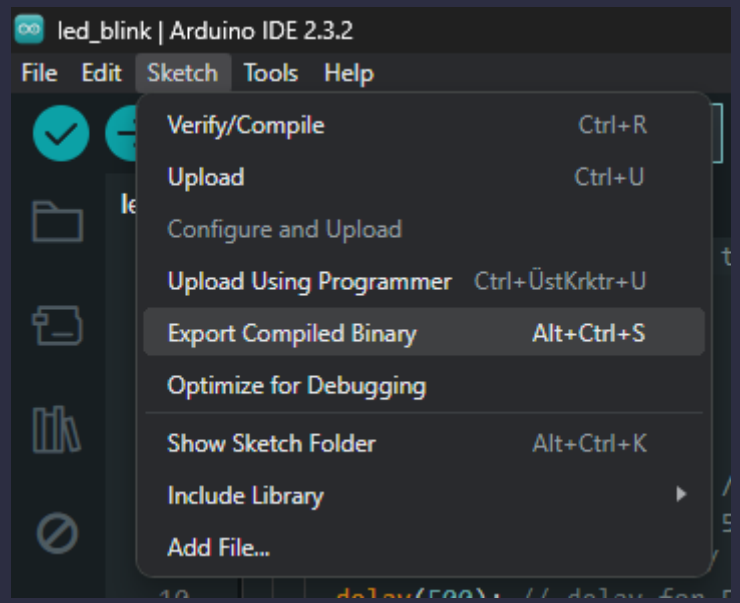
```
int led = 5 ; // led connected to pin 5

void setup () {
  pinMode(led , OUTPUT);
}
void loop () {
     digitalWrite(led,HIGH); // turn on led
    delay(500); // delay for 500 ms
    digitalWrite(led,LOW); // turn off led
    delay(500); // delay for 500 ms
}
```

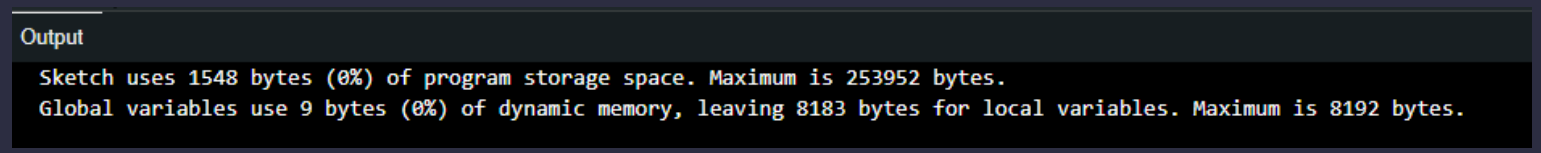

Save the Code

# System Design with Sensors I - Baremetal

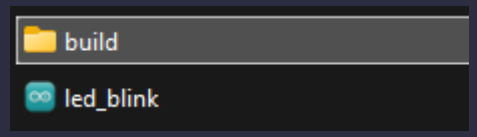
- Ardunio IDE

Compile and Export as Hex




No Errors

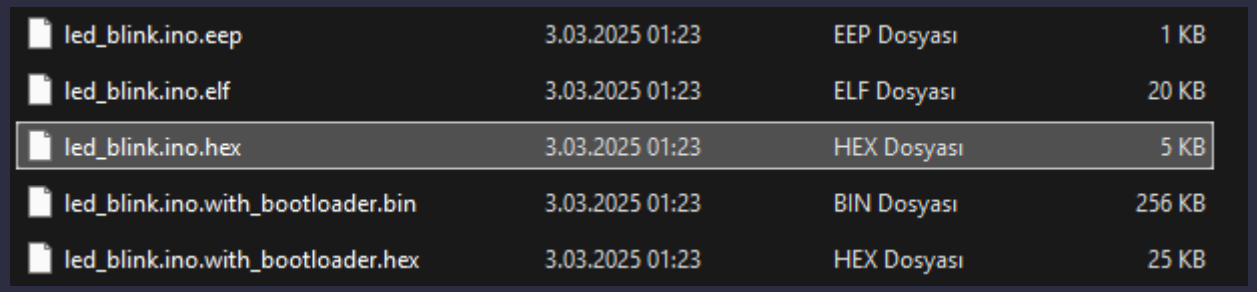



build folder will be created

# System Design with Sensors I - Baremetal

- Ardunio IDE

Compile and Export as Hex

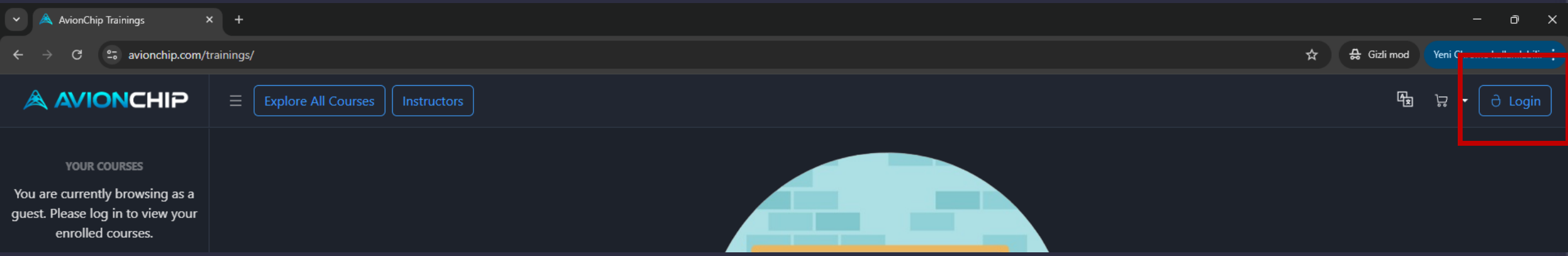



Compiled Hex Code

# System Design with Sensors I - Baremetal

- Practice on Avionchip MCU Platfrom

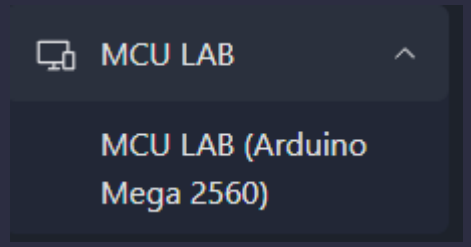
- Go to https://www.avionchip.com/trainings/
- Login with your Marmara University Account



# System Design with Sensors I - Baremetal

- Practice on Avionchip MCU Platfrom

- Find MCU LAB (Arduino Mega 2560) Page from left menu



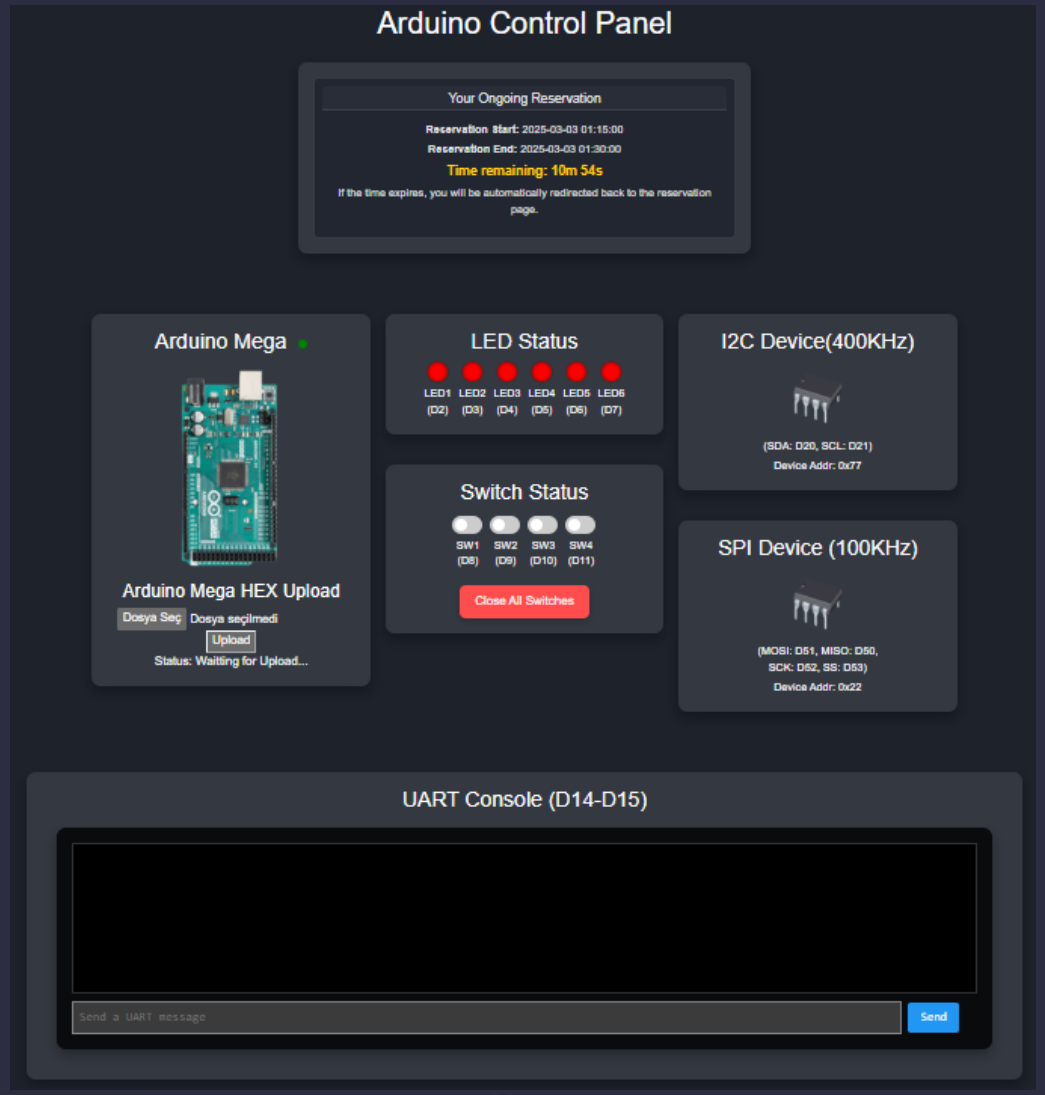
# System Design with Sensors I - Baremetal

- Practice on Avionchip MCU Platfrom
- You will see reservation page
- Limitations
  - 3 hours per day

# System Design with Sensors I - Baremetal

- Practice on Avionchip MCU Platfrom

- MCU Control Page



# System Design with Sensors I - Baremetal

- Practice on Avionchip MCU Platfrom

- MCU Control Page
- **Choose Hex Code and click Upload**

# System Design with Sensors I - Baremetal

- Ardunio IDE

- Digital Read
- Digital Write

```
int led = 5;
int sw = 8;

void setup() {
  pinMode(led, OUTPUT);
  pinMode(sw, INPUT);
}

void loop() {
  int swState = digitalRead(sw);

int delayTime = (swState == HIGH) ? 1000 : 500;

  digitalWrite(led, HIGH);  // LED'i aç
  delay(delayTime);        // delayTime kadar bekle
  digitalWrite(led, LOW);   // LED'i kapat
  delay(delayTime);        // delayTime kadar bekle
}
```

# System Design with Sensors I - Baremetal

- Ardunio IDE

UART (Universal Asynchronous Receiver Transmitter)

```
void setup() {
  Serial3.begin(9600);
}

void loop() {
  if (Serial3.available() > 0) {
    String input = Serial3.readStringUntil('\n');
    input.trim();
    if (input.equals("hello")) {
      Serial3.println("how are you");
    } else {
      Serial3.println("i dont know");
    }
  }
}
```