MA2012 Introduction to Mechatronics Systems Design (Lecture 8)

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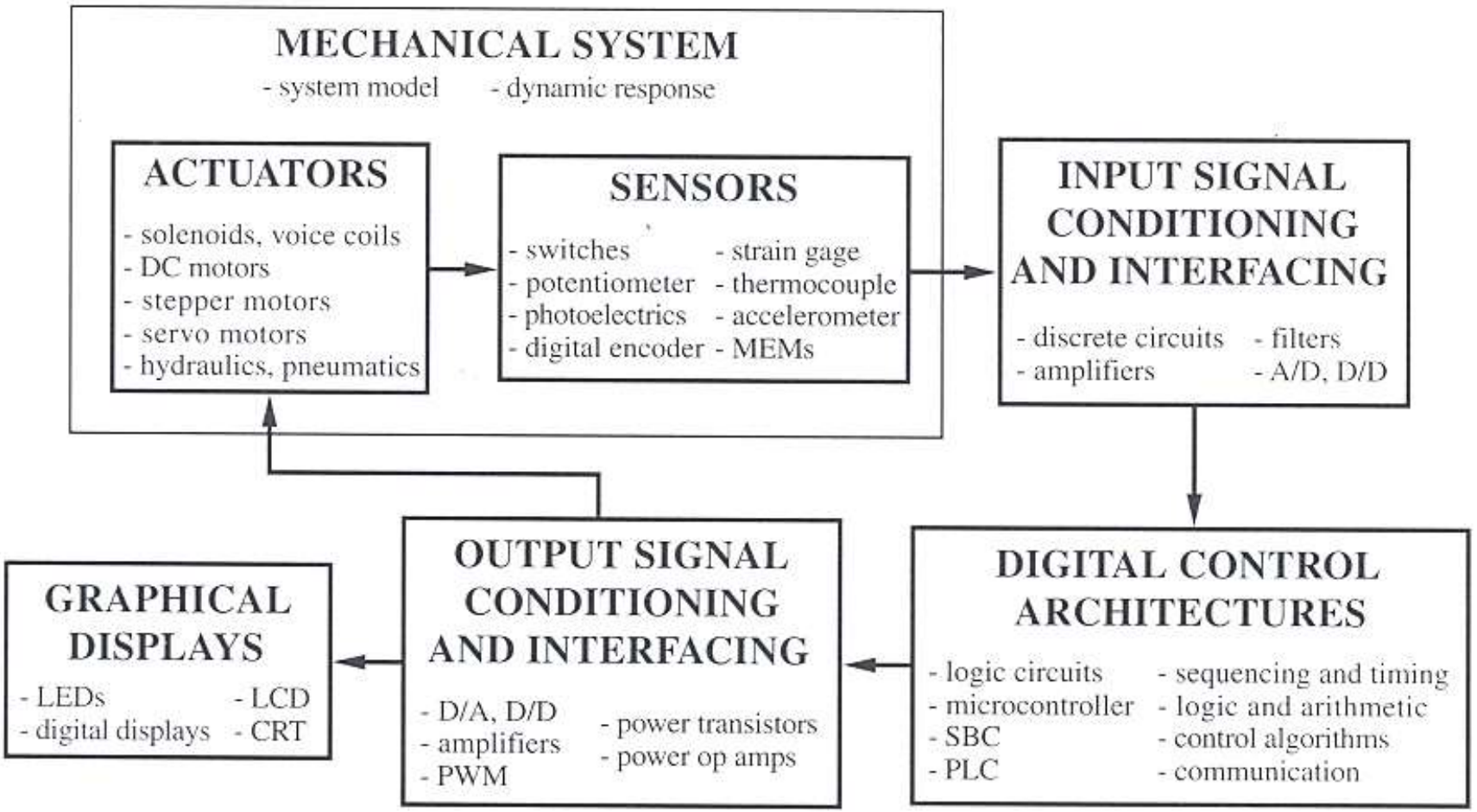
- CA Result
  - Class mean = A+

Lecture 1 – Introduction ★

- Mechatronics System Components & Examples: Car, Printer, etc.

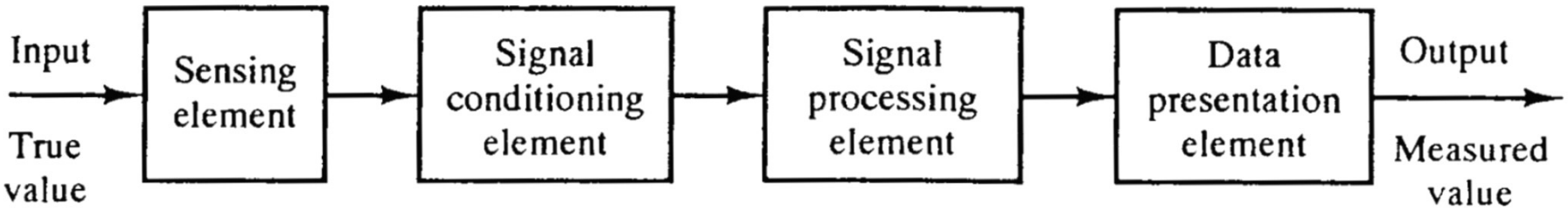


Lecture 2 – Arduino UNO MCU

- ATMega 328 MCU
  - Number of bits, processor speed
  - Memory: RAM, EEPROM, Flash Memory
  - Memory allocation in different application scenarios
- Other components
  - Digital I/O pins, ADC pins, power supply
- Programming Environment: Arduino IDE
- Connecting PC to Arduino Board
- Bootloader Program

Lecture 3 – Sensors ★ ★ ★ ★ ★

- Digital Sensors
  - Switches, Incremental Encoder
  - Interfacing with Digital Sensors
- Analog Sensors
  - Digital Output (e.g. Proximity sensor), Analog Output (e.g. Potentiometer), Digital and Analog Outputs (e.g. accelerometer)
- Acquisition process and elements



Lecture 3 – Sensors ★ ★ ★ ★ ★

- Digitization of analog signal
  - Shannon sampling theorem, Nyquisit frequency, Aliasing
- A/D Conversion, ADC
  - Successive Approximation, Flash Converter
  - Interfacing with ADC

Lecture 4 – Actuators ★ ★ ★ ★ ★

- Direct Current (DC) Motor
  - Construction
    - Brushed vs Brushless
  - Control
    - Pulse Width Modulation (PWM)
    - Inductive Kickback & Diode protection

- Servomotor
  - Working principle
  - Control: Mark length

Lecture 4 – Actuators ★ ★ ★ ★ ★

- Solenoid
  - Construction & Control
- Stepper Motor
  - Construction & Working Principle
    - Unipolar – 2 windings per phase, one for each direction of magnetic field
    - Bipolar – 1 winding per phase, needs a H-Bridge circuit to change direction
  - Control
    - Wave Drive / Single Phase
    - Two Phase Full Step
    - Two Phase Half Step
    - Microstepping

Lecture 5 – Signal Conditioning

★ ★ ★ ★

- Signals & Noise
  - Deterministic vs random signals
  - Noise characteristics & sources
  - Signal-to-Noise Ratio
- Input Signal Conditioning
  - Deflection Bridge: Quarter, Half, Full
  - Op-amps: Inverting, non-inverting, differential, voltage follower, voltage adder
  - Filters: Low Pass, High Pass
  - Averaging
- Output Signal Conditioning
  - Digital-to-Analog Converter

Lecture 6 – Communications

- Interfacing with I/O devices
  - MCU-Initiated
    - Unconditional transfer, no handshaking
    - Conditional transfer (Polling), handshaking is required
  - Device-Initiated
    - Interrupt transfer, handshaking is required
    - Characteristics of Interrupt Service Routine (ISR)
    - Hardware interrupt in Arduino
  - Polling vs Interrupting

Lecture 6 – Communications

★ ★ ★ ★ ★

- Parallel vs Serial Communications
- Universal Asynchronous Receiver Transmitter (UART)
- Data transmission rate
- Synchronous vs Asynchronous communications
- I2C Bus and SPI Bus
  - Characteristics, Communication protocols
  - Advantages
- Wireless communications
  - Bluetooth
  - WIFI

Lecture 7 – Mechatronics Systems

★ ★ ★ ★ ★

1. Understand the task, define the problem
2. Sketch a functional block diagram
3. Decide & select mechatronics components (type, number, communication protocol, etc.) :
   - Digital control architecture
   - Sensors & input interfacing
   - Actuators & output interfacing
   - Display
4. Construct hardware prototype
5. Programme software / firmware

Examination

- Date/Time/Venue: 07 Dec / 1:00 PM / Hall A
- Format:
  - 2h
  - Closed book
  - 4 questions
  - Answer all
- 50% of Final Grade

Exam Scope & Question Types

- Short questions on sensors, actuators, I/O devices and interfacing
  - Given a problem/task/scenario, identify suitable component(s) or techniques and explain choice
- Circuit & Programming
  - Given a circuit, write sub-routines to fulfill certain task requirements.
  - Given a sub-routine, interpret what the codes are trying to do

Exam Scope & Question Types

- Design of mechatronics systems with Arduino UNO MCU
  - Given a problem/task/scenario, design a mechatronics system: description and/or block diagrams
- Interfacing Arduino UNO MCU with sensors and/or actuators
  - Given a datasheet(s) of sensor and/or actuator, answer short questions, sketch simple circuits, do simple calculations, write C++ codes, etc.

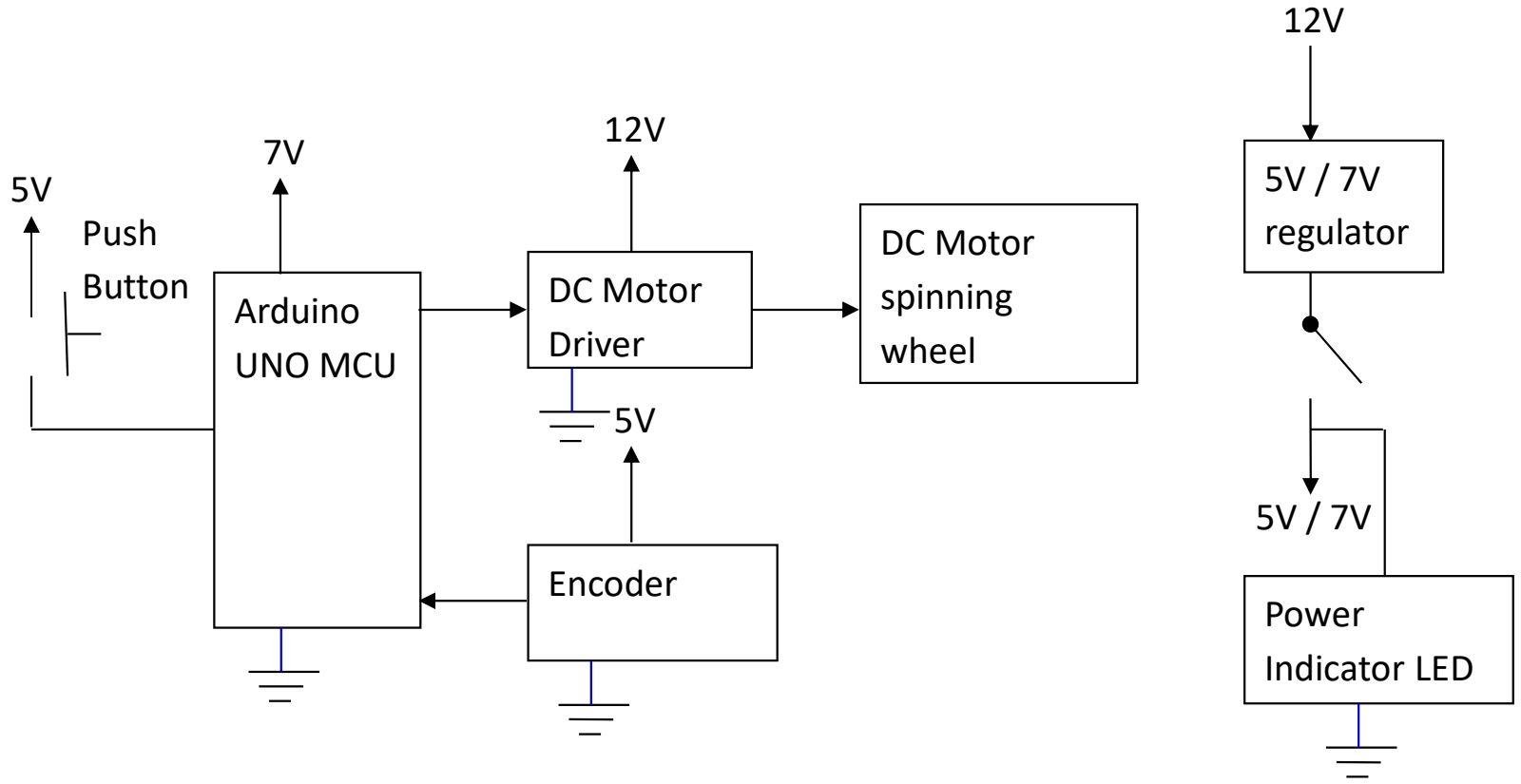
Exercise 1

- You are to design a control system of a spinning lucky draw wheel at an amusement park.
- When a participant presses a button, the wheel will spin at around 30 rpm; when the button is released, the wheel is allowed to spin freely until it stops.
- There are 16 different prizes to be won. Your system has to automatically identify the sector at the 12 o'clock position and display the associated prize on a dot matrix display.

Exercise 1

- Sketch a schematic block diagram to show your design of the control system for this application.
- Indicate and describe clearly in your diagram all the required mechatronic components (Arduino UNO MCU, sensors, actuators, I/O devices, interfacing devices, power sources, etc.) and their relationships. You may assume the system uses a 12VDC battery pack.
- Your answer need to specify only the component type, information on the make and model of components are not necessary

Exercise 1


5V
Push
Button
7V
Arduino
UNO MCU
12V
DC Motor
Driver
5V
DC Motor
spinning
wheel
Encoder
12V
5V / 7V
regulator
5V / 7V
Power
Indicator LED

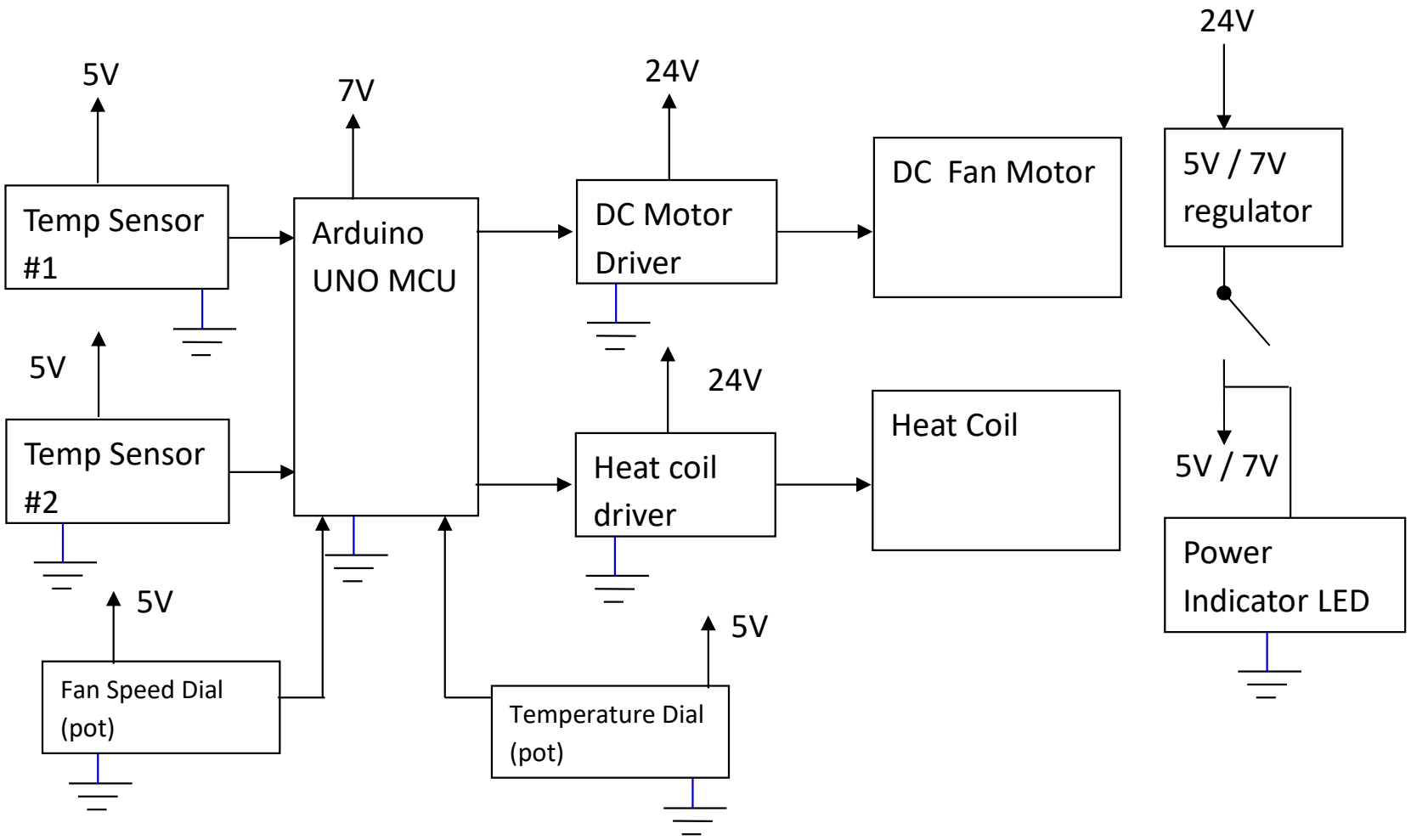
Exercise 2

- You are to design an automatic temperature control system to keep a car warm.
- There are two control settings: temperature & fan speed. Both settings has 3 levels of control: Low, Medium, High.
- In the manual mode, you may independently set the level of temperature and fan speed.
- In the automatic mode, you set the level of temperature (L-M-H) and the computer will adjust the heating coil temperature & fan speed to reach and maintain it within the desired temperature range

Exercise 2

- Sketch a schematic block diagram to show your design of the control system for this application.
- Indicate and describe clearly in your diagram all the required mechatronic components (Arduino UNO MCU, sensors, actuators, I/O devices, interfacing devices, power sources, etc.) and their relationships. You may assume the car runs with a 24VDC battery.
- Your answer need to specify only the component type, information on the make and model of components are not necessary

Exercise 2


5V
7V
24V
24V
Temp Sensor #1
Arduino UNO MCU
DC Motor Driver
DC Fan Motor
5V / 7V regulator
5V
24V
Temp Sensor #2
Heat coil driver
Heat Coil
5V / 7V
5V
5V
Fan Speed Dial (pot)
Temperature Dial (pot)
Power Indicator LED

Exercise 3

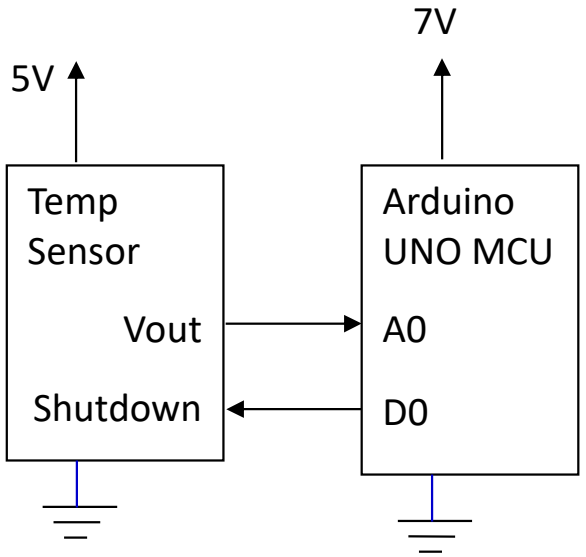
- The application described in Ex. 2 requires 2 temperature sensors to be mounted in the car, one near the driver's seat and the other one near the back row seat. Given the datasheet of Analog Devices TMP3x Low Voltage temperature sensor. Answer the following questions:

Exercise 3

- Describe how can we use the $\overline{\text{SHUTDOWN}}$ function to minimize the power consumed by the temperature sensor when the car engine is off.
  - MCU sends a Logic 0 (LOW) to the $\overline{\text{SHUTDOWN}}$ pin
- Which packaging type (SOT-23/SOIC_N/TO-92) should we choose?
  - SOIC_N or SOT-23. (See Datasheet pg 9, section Shutdown Operation)

Exercise 3

- How would you interface this sensor with an Arduino UNO MCU? Describe in words and sketch a schematic diagram.
  - The temperature sensor Vout pin is connected to one of the Analog Input pins of Arduino UNO MCU
  - The Shutdown pin is connected to a Digital I/O pin.

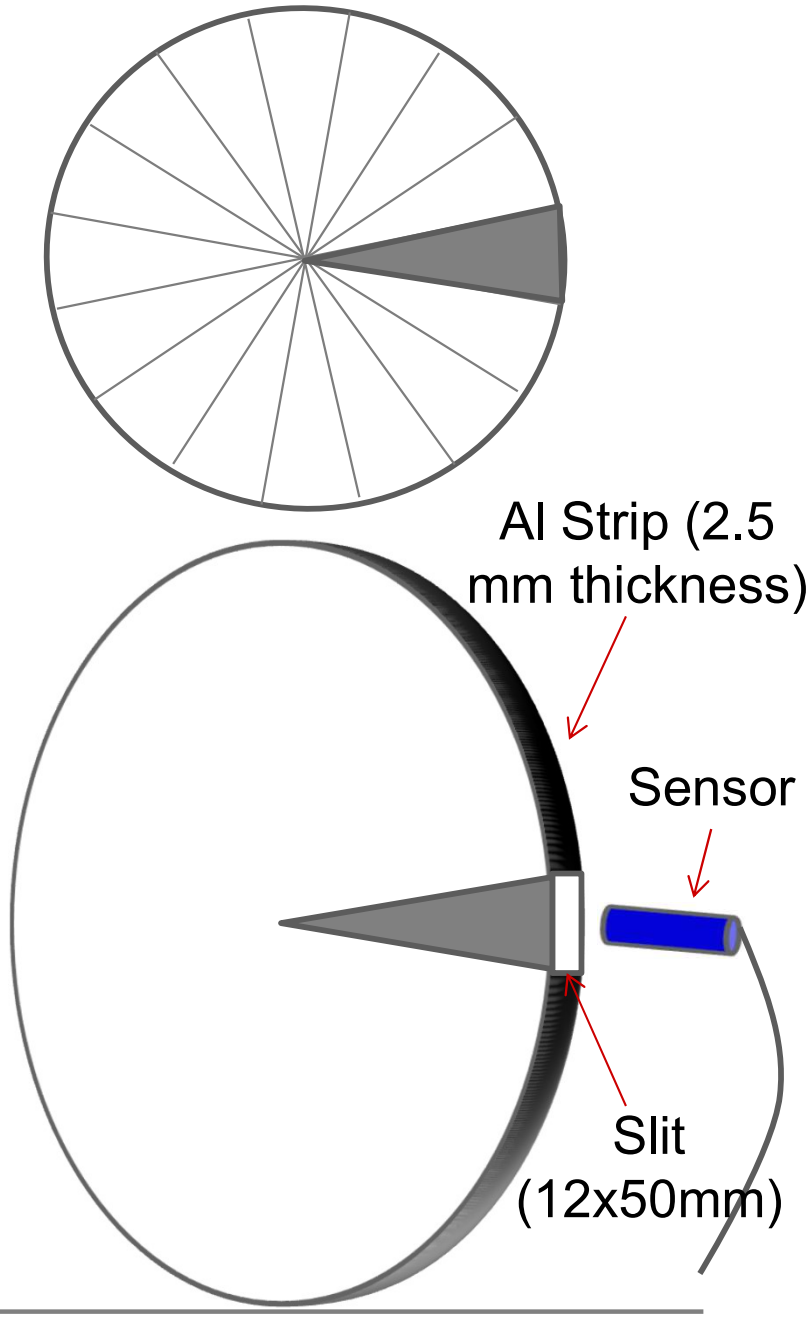


Exercise 3

- If the car is designed for all weather conditions, i.e. –30 to +45°C, which model (35/36/37) should we choose? Why?
  - All models can be used but TMP36 should be chosen because the scale factor is rated in this temperature range, i.e. performance can be guaranteed.
- If the car is designed for sub-tropical conditions, i.e. +5 to +30°C, and it is desirable to maximize the sensitivity, which model should we choose? Why?
  - TMP37. Because it is the most sensitive (20 mv/deg).

Exercise 4

- The game in Ex.1 is changed such that only 1 out of 16 sectors will win the grand prize, and all others win nothing. The design of the system is such that a sensor senses no object (slit) when a prize is won.
- Given the datasheet of Omron proximity sensor E2EM. Answer the following questions:



Exercise 4

- If the distance between the sensor and the rim of the wheel is 10mm, which model should you use?
  - E2EM-X30MX. Refer to pg 4 bottom right graph, see plot for Aluminum.
- If it is required to send a LOW to a MCU when the slit is detected, should you choose NC or NO type?
  - NO. Because when the slit (i.e. no object) is detected, the output is LOW.
- Discuss the trade-off of selecting shielded vs unshielded model.
  - Unshielded: longer sensing distance but more noise
  - Shielded: vice versa

AY16/17 Q2

- A mechatronics engineer implemented a measurement system using an Arduino UNO MCU. The measurement system has a digital temperature sensor and an analog accelerometer to monitor the conditions of a piece of equipment. The temperature sensor records the ambient temperature of at a sampling frequency of 10 Hz. A 4-digit Liquid Crystal Display (LCD) is used to show real-time measurement of the temperature (see Figure 1) with 2 decimal points. The accelerometer is used to measure the vibration of the equipment caused by movement activities in its vicinity and is sampled at 200 Hz.

AY16/17 Q2

- An operator observes that the least significant digit of the LCD is fluctuating all the time while the ambient temperature is held constant. Explain the cause of this observation. (2 mark)

  This fluctuation is caused by random or white noise.

- The temperature sensor has a resolution of 12-bit and the sensing range is from 10 – 90°C. The fluctuation is only in the range of ± 1 bit from the true temperature. Given that the true temperature is 30.00°C, what are the 3 possible temperatures which the display will show? (9 marks)

  12 bit is equivalent to 2^{12} = 4096 levels

  Temperature range = 90 – 10 = 80°C

  Resolution = 80 / 4,096 = 0.02°C

  The 3 possible temperatures to be displayed are 29.98, 30.00 & 30.02.

AY16/17 Q2

- Suggest 3 possible ways to make the temperature reading shown on the LCD to stop fluctuating so frequently. (6 marks)

  Any 3 of the following:

  - Use a lowpass filter
  - Perform a moving average
  - Display only 1 decimal point
  - Update display every minute (or any time period significantly longer than sampling period)
- An analysis of a short period of recording by the accelerometer reveals that the signal is made up of a 1 Hz signal caused by a person walking pass the equipment, a 50 Hz noise caused by powerline hum, and random noise. Suggest how this powerline hum can be removed without affecting the 1 Hz signal. (3 marks)

  To use a lowpass filter with a cut-off frequency between 10-40 Hz.

  Or to use a bandstop filter centered at 50Hz.

AY16/17 Q2

- Why is the powerline hum not observed in the temperature sensor recording? (3 marks)

  Because the sampling frequency is lower than the Nyquist frequency to sense the 50 Hz powerline hum.

- If a digital accelerometer is used instead of an analog one, would the powerline hum be still unobservable? (2 marks)

  Yes

AY19/20 Q2

a) Name two advantages and two disadvantages of DC motors as compared with Stepper motors.

(4 marks)

- Advantages of DC Motor vs Stepper Motor (any 2):
  - Easier to control in velocity control mode
  - Possible to control in torque control mode
  - Cheaper to implement in velocity control applications
  - Higher torque in high speed applications
- Disadvantages (any 2):
  - Harder to control in displacement/position control mode
  - Lower holding torque in positioning applications
  - Lower torque at low speed applications
  - More expensive to implement in positioning applications

AY19/20 Q2

(b) In general, a DC motor may be controlled in speed control mode or torque control mode. Explain how you can use an Arduino UNO MCU only (i.e. without a peripheral driver) to control a DC motor in these two control modes.

(4 marks)

- Speed control mode: Not possible, need a driver
- Torque control mode: not possible with Arduino UNO

AY19/20 Q2

c. When controlling a DC motor, it is mandatory to add a flyback diode in the circuit, as illustrated in Figure 2. Explain why this is necessary.

- (4 marks)

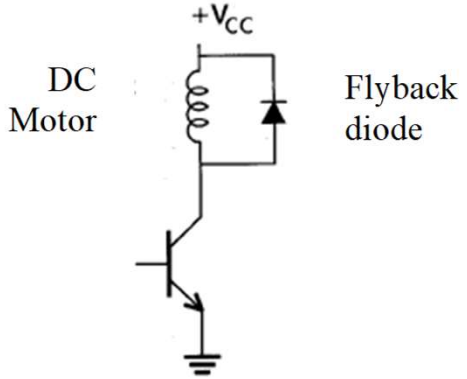


Figure 2: A DC motor circuit with a flyback diode.

- The steady-state current though an inductor, cannot immediately go to zero when the switch (physical or transistor) is opened. The changing current induces a voltage across the inductor, making the potential of the ground end of the inductor greater than the Vcc end, and will cause the switch to 'blow up'. Kickback or flyback diode protects the switch from blowing up.

AY19/20 Q2

d. There are several ways to control a unipolar Stepper motor. State one advantage of each of the three popular control methods: Wave Drive, Two Phase Full Step and Two Phase Half Step.

- (3 marks)

- Wave Drive: Simplest to control
- Two Phase Full Step: Highest holding torque
- Two Phase Half Step: Highest positioning resolution/accuracy

AY19/20 Q3

- A geologist wishes to map the profile of a cave with a river running through it. As illustrated in Figure 5, his idea is to use a remote control boat to go upstream, carrying a laser scanning device.

  The laser scanning device is made up of an Arduino UNO MCU, a Flash memory module, a pair of laser range sensors, each attached to a tilt motor which has a range of 135 degrees.

  The boat is equipped with a battery powered power-supply (also provide power to the laser scanning device), a rudder steering motor, a motor with propeller, an ultrasonic speed sensor to measure the boat speed, an Arduino UNO MCU and a wireless communication module.

  The remote controller consists of an Arduino UNO MCU, a wireless communication module, a battery and two potentiometers for speed and steering control.

  Sketch a schematic block diagram to show your design of the control systems for this application. Indicate and describe clearly in your diagram all the mechatronic components (Arduino UNO MCU, sensors, actuators, I/O devices, interfacing devices, power sources, etc.) and their relationships to each other. You may make appropriate assumptions to add new components (e.g. switches), but you need to state them clearly.

  Your answer need to specify only the component type. Information on the make and model of components are not necessary.

  (25 marks)

AY19/20 Q3

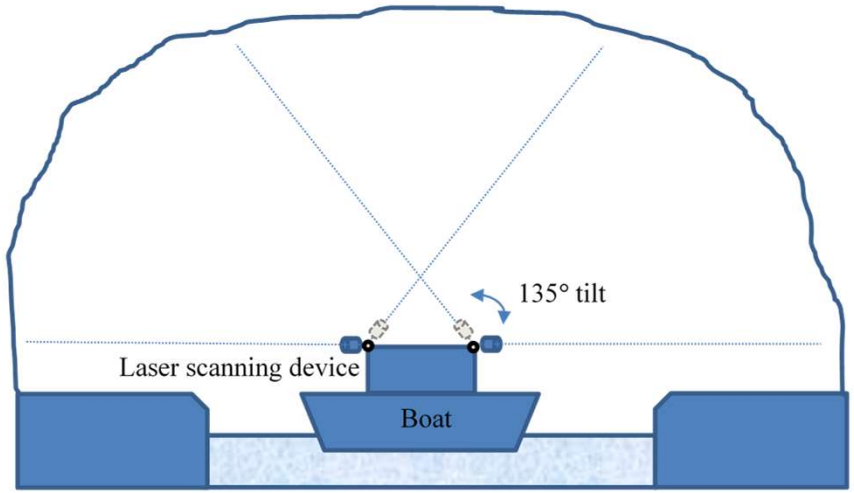
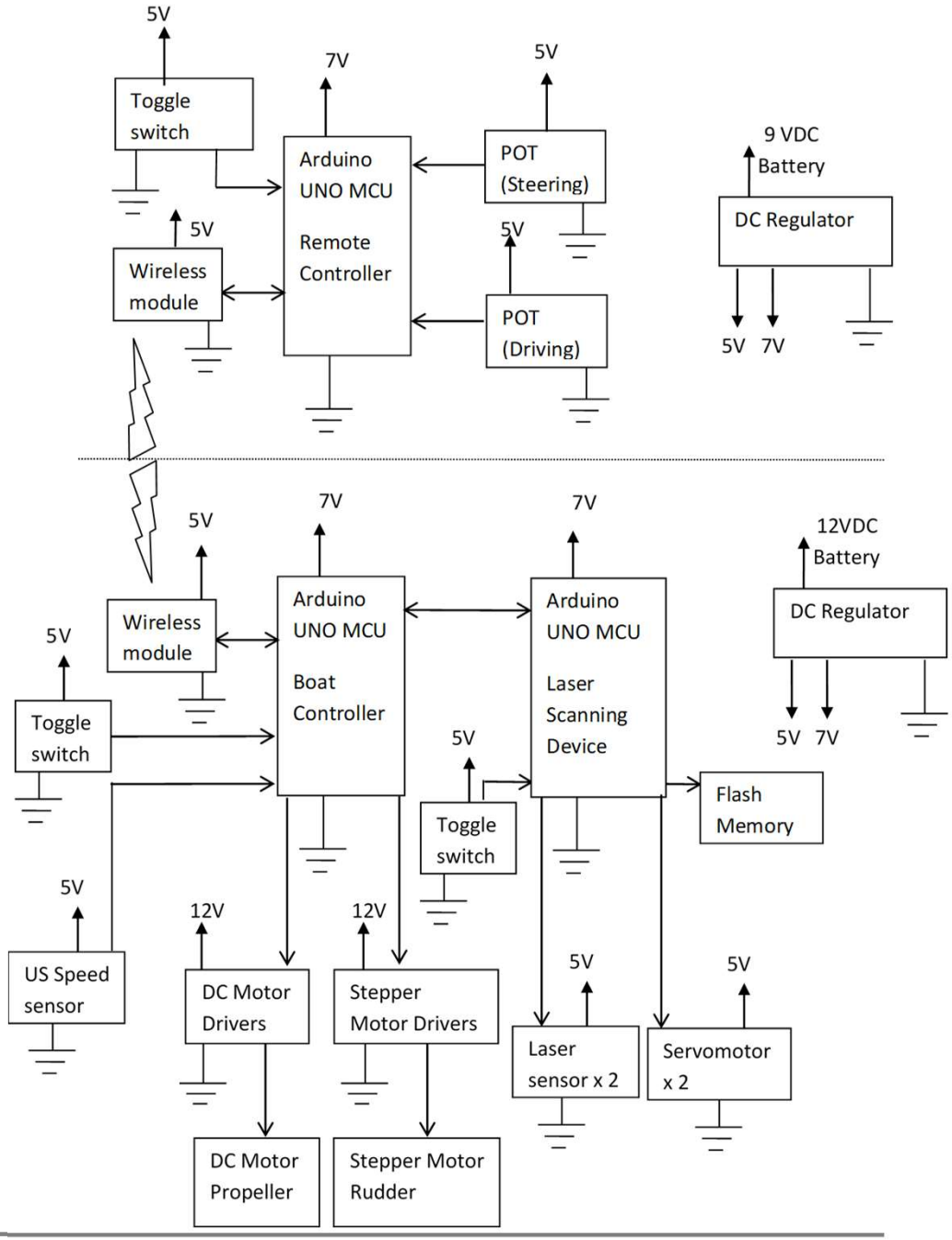


Figure 5: A remote control boat carrying a laser scanning device.



Homework

- AY1516 Q4
- AY1617 Q4
- AY1718 Q2
- AY1920 Q4
- AY2021 Q4
- AY2122 Q3
- AY2223 Q4
- Solutions shall be posted on 30 Nov

Good Luck!