Mechatronics Systems Design Laboratory

ECE 491

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Upcoming Checkout

- This week:
  - DC – DC Converter – Lab 6
- Next week:
  - DC – DC Converter – Lab 6

Quiz 2 (2/28/2017)

- 30 min at start of class
- Topics:
  - DC-DC converter
  - OP-Amps
  - Encoders (incl. today)

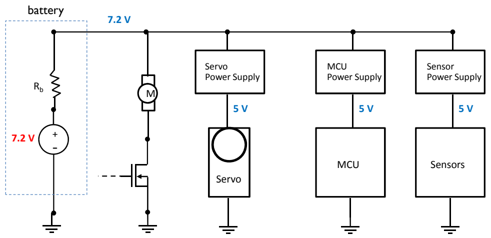
PCB Board 1

- Designs to John by Wednesday 3/8/2017
  - Noon
- Use template provided for you
- Shall contain:
  - power supply (DC-DC)
    - Remember disconnect switch
  - Motor controllers

Midterm (3/14/2017)

- Open Book/Open Notes
- Topics:
  - Motors
  - Motor controllers
  - FET review
  - DC-DC converter
  - OP-Amps review
  - Encoders (incl. today)

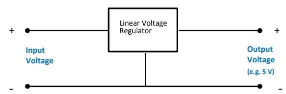
Review: Power Supply for Autonomous Car



Schematic of the required power supply for the sub-systems

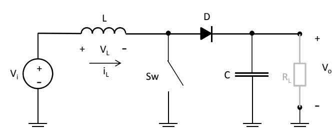
Power Supply 1: Linear Voltage Regulator

- Reduces the supply voltage to a stable value set value
  - Output voltage less than input voltage
  - A variable (controlled) resistor
- Key parameters
  - Output voltage (e.g. 5 V)
  - Input voltage range
    - Output current
    - Dropout
- E.g.: LM2940CT-5.0/NOPB
  - 5 Vout
  - 0V to 26V input
  - 1 A max output
  - 500mV Dropout



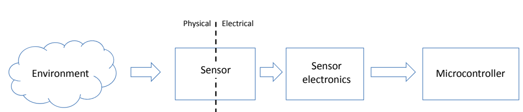
Power Supply II: Boost Converter

- Used to boost the input voltage
- Uses a storage inductor as the storage element for the boost stage



Sensors - An Introduction

- Obtains the information about the environment
- Provides transduction between the physical (mechanical) and electrical domains
  - Transduction: Conversion of energy between energy domains

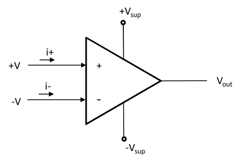


Review – Operational Amplifiers

- Operational Amplifiers (OpAmps) are commonly used to amplify (precondition) sensing signal for input to a microcontrollers
- OpAmps are analyzed as ***ideal***

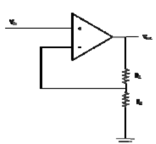
Ideal OP-Amp: $\boxed{V_{out} = A(V^{+} - V^{-})}$

- High input impedance (i+ ≈ 0, i- ≈ 0)
- Low output impedance
- Infinite gain (A is very large)

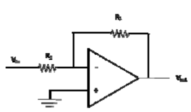


Review – Operational Amplifiers

- Two main configurations:



Non-inverting Amplifier



Inverting Amplifier

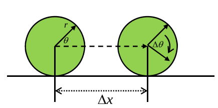
Optical Rotary Encoders and Velocity Sensing

- Velocity sensing is necessary for a car to reach a set velocity
  - Recall $\tau \propto i_m$
  - To reach the desired velocity, the car has to accelerate, i.e. increase i_m
  - Once desired velocity is reach the car has to coast, reducing i_m to counteract friction and drag
  - I_m must be larger to maintain same velocity if traversing an incline
- Velocity = distance / time
- Assuming a no-slip condition:

$$\Delta x = \Delta\theta \cdot r$$

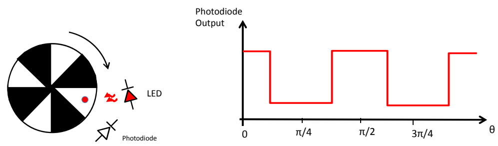
- Resulting velocity:

$$v = \frac{\Delta x}{\Delta t} = \frac{\Delta\theta}{\Delta t} \cdot r = \omega \cdot r$$

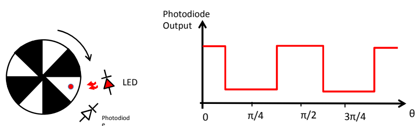


Optical Rotary Encoders and Velocity Sensing

- Optical Rotary Encoders:
  - Non-contact way to measure rotation/angular velocity
  - Can be purchased enclosed, or can be build onto the car wheel base
- Basics of operations:



Optical Rotary Encoders and Velocity Sensing



- Two ways to measure velocity:
  1. Count number of transitions (edges) within a fixed amount of time.
  2. Measure time between two transitions, i.e. the width of pulse or valley.
- Depends on the number of transitions v.s. sampling rate

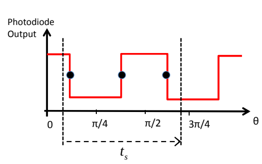
Optical Rotary Encoders and Velocity Sensing

- Count number of edges in a fixed amount of time:

$$\boxed{v = \frac{n\Delta\theta_{e-e}}{t_s}\cdot r}$$

where t_s is sampling time, n is the number of transitions, and θ_{e-e} is the angle between transitions, in this case π/4.

Error: $\pm\frac{\Delta\theta_{e-e}}{t_s}\cdot r$



Optical Rotary Encoders and Velocity Sensing

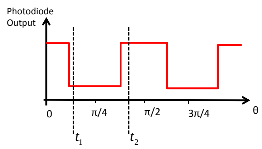
- Measure time between transitions:

$$\boxed{v = \frac{\Delta\theta_{e-e}}{t_2 - t_1}\cdot r}$$

where t_1 is the time of first transition, t_2 is the time of second transition θ_{e-e} is the angle between transitions, in this case π/4.

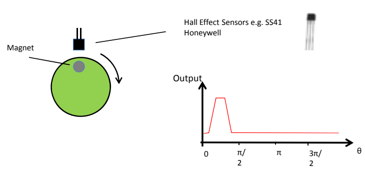
Error: $\pm\frac{\Delta\theta_{e-e}}{t_e}\cdot r$

where t_e is the sampling interval.



Velocity Sensing – Alternative Approaches

- Optical encoder is just one way to measure velocity
- Other approaches include:
  - Back EMF from the motors
  - Other types of proximity sensors to mark a revolution of the wheel
    - Good example is Hall-effect sensors



Summary: Optical Rotary Encoders and Velocity Sensing

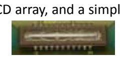
- Non-contact way of measuring rotation, can be integrated on the wheel
- Assuming no-slip conditions, wheel rotation corresponds to distance traveled
- An optical rotary encoder wheel can be used to measure rotation
- Two approaches:
  - Measure time between transitions
  - Count number of transitions within a time interval
  - Which approach to chose depends on: velocity, sampling time, allowable error
- Other approaches, such as sensing back EMF or hall effect (magnetic) sensing can be used to estimate the velocity

Optical Line Camera and Line Following

- A vision system is a key component in any autonomously driving car
- Optical camera projects an image onto a surface composed of light sensitive pixels
- Charge Coupled Device (CCD) image sensor:
  - An array of light sensitive pixels fabricated on a silicon chip, used to detect projected images
  - 2D array an essential component in many digital cameras

wikipedia

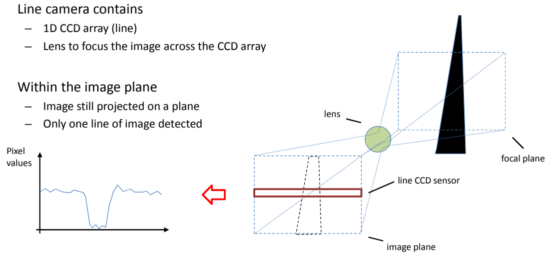
- Sophisticated image reconstruction algorithms usually need
- Line or edge following can be constructed using a 1D CCD array, and a simplified algorithm.



wikipedia

Optical Line Camera and Line Following

- Line camera contains
  - 1D CCD array (line)
  - Lens to focus the image across the CCD array
- Within the image plane
  - Image still projected on a plane
  - Only one line of image detected



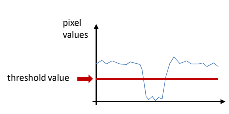
Optical Line Camera and Line Following

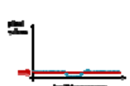
- Detecting line center
  - Thresholding an effective method
  - NOTE: need to adjust the level of thresholding as well as the exposure level
- Pixels (image elements) as array of 1's and 0's
- Simple algorithms to detect line locations
  - Pixel counting

{1,1,1,1,1,1,0,0,0,0,0,1,1,1,1,1,1}

line width

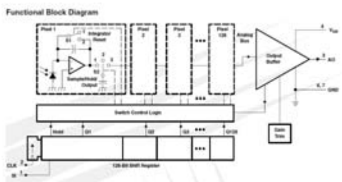
distance to center

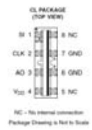




Optical Line Camera and Line Following

- Recommended line camera: TAOS TSL1401CL
  - 128 x 1 linear optical sensor array
  - 3 – 5 V V_{dd} power supply

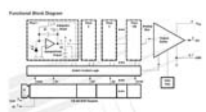




Optical Line Camera and Line Following

- Sensor functionality:

$$AO = V_{out} = V_{drk} + R_e \cdot E_e \cdot t_{\mathrm{int}}$$



- The pixels are serially read
- SI marks the start of the readout sequence
- Each clock pulse marks the transition to a new pixel, accessible through AO
- During reading, pixels are in parallel exposed
- Exposure time (integration time):

$$t_{\mathrm{int}} = (129-18) \cdot t_{CLK} + t_{qt}$$

Optical Line Camera and Line Following

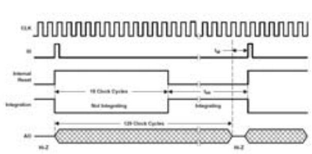
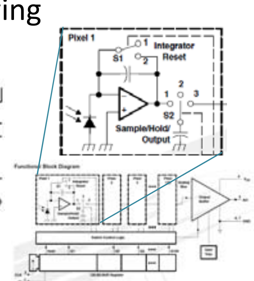
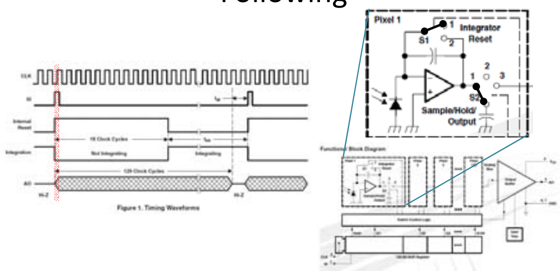


Figure 1. Timing Waveforms



Optical Line Camera and Line Following



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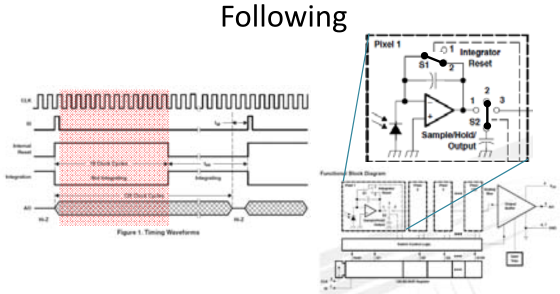

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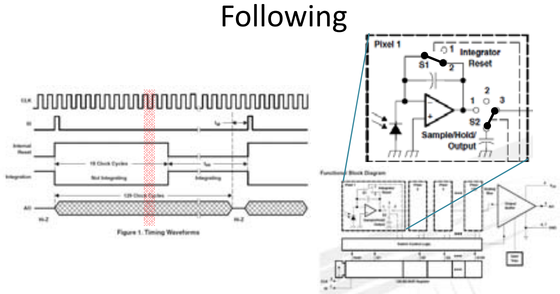

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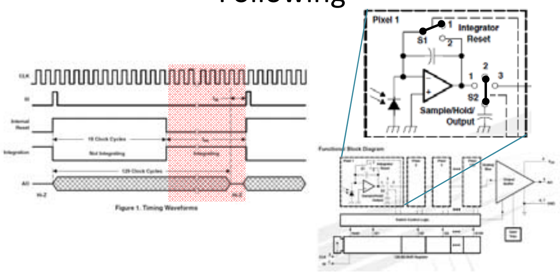
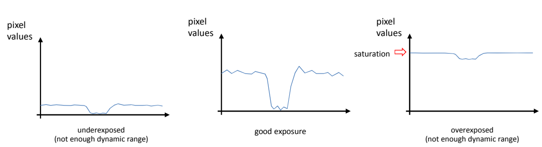


Exposure Adjustment

- Recap sensor functionality: $AO = V_{out} = V_{drk} + R_e \cdot E_e \cdot t_{int}$
  $t_{int} = (129 - 18) \cdot t_{CLK} + t_{qt}$
- Note exposure time is proportional to t_{int}
- Can adjust exposure by adjusting the integration time !
  - Lower CLK frequency (readout) in low-light conditions
  - Higher CLK frequency (readout) in high-light conditions
- Potential problem
  - Slow down control loop
  - CLK exceeds the ADC frequency
- Solution:
  - Two cycles, 1) exposure and 2) readout.
  1. Fast sequence – expose only, ignore readout on AO
  2. Slow sequence – readout only, read stored data in cycle 1)

5 KHz < f_{clock} < 8 MHz

Exposure Adjustment



- Exposure should be adjusted to maximize dynamic range
  - Can be done online during line following
  - Can be done during the control loop

Summary: Optical Line Camera and Line Following

- A 2D light-sensitive pixel array is used in cameras for image capture
- A 1D pixel array (line) can be used for line detection – line camera
- Can be used for optical line following
  - Focus sensor on the line
  - Thresholding can be used to determine the center of the line
- Line camera provided with the kit uses TAOS TSL1401CL sensor
  - 128 pixels
  - Variable integration (exposure) time
  - Sequential (serial) output via AO, controlled through CLK and SI
- Exposure can be varied to accommodate changes in lighting conditions
  - Changing the CLK frequency
  - Can be done dynamically to account for changes in light conditions

Module Outline

- Introduction to Feedback Control
- Nonholonomic Modeling of an Autonomous Car
- PID Control
  - Velocity control
  - Steering
- Summary and Conclusion

Introduction to Feedback Control

- Microcontroller provides control signals to the actuators
- Control System:
  - Describes the interaction between the microcontroller and the environment to perform some *useful* task

  - A control system where interaction only is one way, is called **open-loop control**

Introduction to Feedback Control

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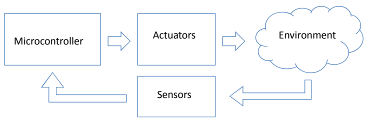

  - A control system where interaction only is two way, is called **closed-loop control**
  - Most control systems are closed-loop

Introduction to Feedback Control

- Control System:
  - System that describes the control algorithm and the interaction with the environment
- Control System Diagram:
  - Symbolic description of the control system