



UiO : University of Oslo

FYS3240- 4240

Data acquisition & control

Exam preparations

Spring 2024



Bekkeng 19.05.2024

Oral Exam

- Oral examination
- Exam list (data and time for each candidate) will be published also on the FYS3240 course web page.
- 30 minutes examination.

Fra kurssiden: Kort om emnet

- Emnet gir en innføring i datainnsamling og kontroll i PC-baserte systemer og embedded-systemer, for bruk innen instrumentering og styring. Kurset tar for seg treghetssensorer, innsamling av data fra disse sensorene, prosessering av sensordata og hvordan sensorene benyttes i et system med tilbakekobling. Emnet gir også en innføring i utviklingsmiljøet LabVIEW og i bruk av Arduino.

Fra kurssiden: Etter å ha fullført emnet

- kan du programmere Arduino.
- kan du programmere i utviklingsmiljøet LabVIEW.
- kan du forklare et PC-basert datainnsamlingssystem.
- kan du forklare og diskutere treghetssensorer og hvordan disse kan brukes innen navigasjon, orienteringsbestemmelse og kontroll.
- kan du forklare estimering og datafusjon.
- kan du forklare grunnleggende kontrollalgoritmer.

Curriculum FYS3240 & FYS4240 - spring 2024

Lecture notes

Slides marked with **Extra** (in the top right corner) are not part of the curriculum (only for information).

Laboratory exercises

- Lab 1 – 4 for FYS3240
- Lab 1 – 5 for FYS4240

Reference papers:

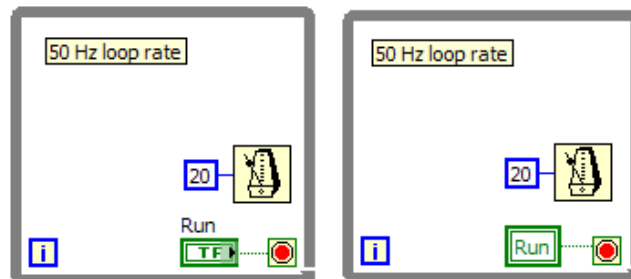
- Stochastic models, estimation and control (by Maybeck)
- An Introduction to the Kalman Filter (by Welch and Bishop)
 - Section 1 and section 3

**Questions you should be able to
answer on the exam**

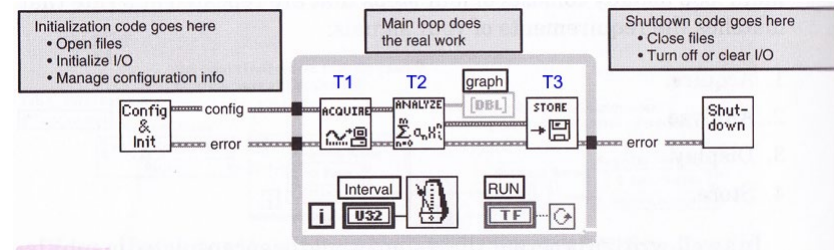
LabVIEW

- Note: you will not be asked to do LabVIEW programming with pen and paper.
- Can you list three advantages of using LabVIEW for data acquisition?
- Explain dataflow programming in LabVIEW.
- Why us / not use Express VIs ?
- Can you give some examples of data types used in LabVIEW and explain how you can see the data type from the block diagram.
- Does LabVIEW support parallel programming (multithreading) ? Explain how.
- How can we synchronize two loops running in parallel ?
- Explain this LabVIEW code...

Just as an example of LabVIEW code:



LabVIEW II

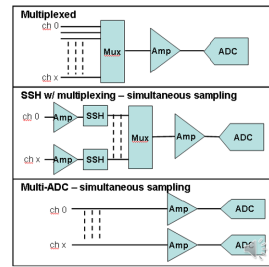


- Describe the architecture for a sequential DAQ design, and the problems associated with using such an architecture.
- Explain the producer-consumer architecture and why it is used.
- Why use queues (not local/global variables) to send data and messages between while-loops ? How is the queue implemented?
- Why should we in general avoid/limit the use of local and global variables (and instead use wires on the diagram/between sub-VIs)?
- What is a sub-VI?
- What is a Cluster in LabVIEW? Compare also with Arrays. List some advantages of using Clusters.
- Why can it be very useful to be able to simulate a DAQ card ? How can we do that in LabVIEW ?
- Why can point-by-point (PtByPt) functions be useful instead of using block (array) based functions?

Computer buses and interfaces

- Explain the difference between synchronous and asynchronous serial data communication.
- You should be able to list at least three different serial data busses and explain them briefly.
- How did we transfer data between the Arduino board and LabVIEW using a cabled connection in the labs?
 - In terms of datatypes, “protocol” etc.
- Explain UDP and give examples of typical use.
- What is a jumbo frame, and why use it?
- What is Manchester encoding and why use it or similar types of encoding?
 - Does the encoding affect the data bandwidth (number of actual data bits transmitted per second)? Explain.

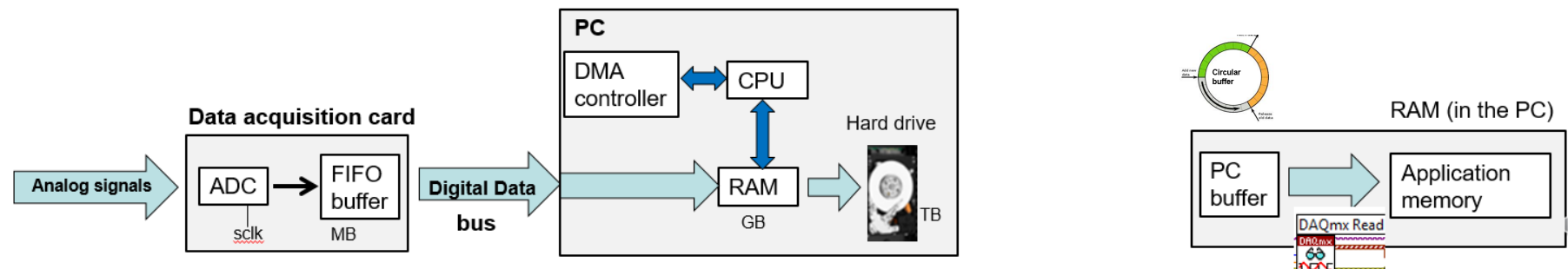
Analog front-end electronics & sampling



- What happens if your DAQ input impedance is too low?
- Explain single-ended vs. differential signals and their use.
- Explain typical signal conditioning required before A/D-conversion.
- Explain sampling and anti-aliasing
 - Nyquist
 - Oversampling – including advantages of using it
 - Why is an analog filter usually required before the ADC in a DAQ-system?
- Explain ADC architectures and ADC errors
- Why use a zero-phase digital filter and when can it be used?

PC-based data acquisition

- Explain Interrupts vs. DMA
- What is hardware acceleration
- Explain software timing vs. hardware timing
- Explain data transfer from DAQ-card to hard drive/solid-state drive
- Why are buffers used, what types and where?
 - Circular buffer (PC buffer), FIFO buffer, overwrite and overflow errors
- How to increase the signal-to-noise-ratio (SNR) in a DAQ-system?
- Why use averaging of datasamples ?
- File types – advantages, write speed, file size
- What is Unbuffered File I/O and why use it?
- What would be the advantages/disadvantages of sending/storing raw data (integer values) instead of converting to floating point values first?



PC-based data acquisition

- Explain real-time processing (online) vs. post-processing (off-line).
- Explain Start trigger and Reference (event) trigger.
- Why use circular buffers in video acquisition ?
- You are told to make a file format to store video data. Can you suggest a structure and explain your choices.
- How would you store time stamps in your file ? Explain
- What are the advantages of using PXI systems ?
- Can you give an example of data instability, and how we can avoid such problems ?

Arduino

- Explain this code...

It is expected that you understand (and can write) basic code for Arduino.

```
#include <Arduino_LSM9DS1.h>

void setup() {
  Serial.begin(9600);
  while (!Serial);
  Serial.println("Started");

  if (!IMU.begin()) {
    Serial.println("Failed to initialize IMU!");
    while (1);
  }

  Serial.print("Accelerometer sample rate = ");
  Serial.print(IMU.accelerationSampleRate());
  Serial.println(" Hz");
  Serial.println();
  Serial.println("Acceleration in G's");
  Serial.println("X\tY\tZ");
}

void loop() {
  float x, y, z;

  if (IMU.accelerationAvailable()) {
    IMU.readAcceleration(x, y, z);

    Serial.print(x);
    Serial.print('\t');
    Serial.print(y);
    Serial.print('\t');
    Serial.println(z);
  }
}
```

Arduino II – General questions

- Can you list some advantages of using Arduino ?
- What is the advantage of sending sensor data from the Arduino board to the PC as text (ASCII) strings ?
- What is in general the disadvantage of sending sensor data as text (ASCII) strings ?
 - And what could we do instead?
- What is the **JSON** protocol, and why use it or not use it?
 - Hint: Self Descriptive protocol

Navigation and attitude

- Explain relative positioning (INS) vs absolute positioning (GNSS)
- Why are INS and GNSS complementary ?
- What is an inertia reference frame ?
- Explain definitions of reference frames

- ECEF
- ECI
- Body
- Local level (NED or ENU)
- Sensor

- When do we have to take into account the rotation of the Earth ?
 - With other words, when can we not say that ECI (i-frame) can be approximated with ECEF (e-frame)?

- Hint: remember “low and slow”

$$\mathbf{a}^i = R^{ie} \left(\mathbf{a}^e + \underbrace{2\boldsymbol{\Omega}^{ei} \mathbf{v}^e}_{\text{Coriolis acceleration}} + \underbrace{\boldsymbol{\Omega}^{ei} \boldsymbol{\Omega}^{ei} \mathbf{r}^e}_{\text{centripetal acceleration}} \right)$$

Navigation and attitude II

- When can we use a local level frame (such as ENU or NED), and what are then our approximations ?
- What kind of sensors can be used to measure orientation?
 - You must also understand how gyros, accelerometers and magnetometers can measure orientation.
- How can we represent an object's orientation (attitude) ?
 - Explain at least one representation (DCM, Euler angels, **quaternions not covered**)
- Why is it important to know orientation (attitude) ?
 - Give some examples
- What do we mean with heading ?
- Can we use the gravity vector alone to determine heading ?
- Can we use the Earth magnetic field vector alone to find heading ?
- What is the advantage of a tilt-compensated magnetic compass and how can we make it
 - Which sensors are used, when can we use it/not use it?

Inertial navigation

- Explain the principles of inertial navigation
- What is an IMU and an INS ?
- What does an accelerometer measure?
 - Hint: f
 - When static
 - When in motion
 - When in free fall (in vacuum)
- Tilt sensing with an accelerometer – can we measure roll, pitch and yaw (heading) angles ?
- How does the INS position error change with time ?
 - explain

Inertial navigation II

- Explain typical systematic errors
- Explain typical random errors
- What are typical errors that we need to include in a model of a gyroscope?
- What is the effect of an uncompensated bias error in the gyroscope and accelerometer, when used in an INS?
- Why do we need to calibrate a magnetometer? Explain one method to perform a calibration.
- Explain a method to determine heading if an object/vehicle has a velocity different from zero

Data fusion & estimation

- What is estimation/data fusion?
- Why do we need an estimator?
- Explain the advantages of multi-sensor data fusion
- Why is it so common to combine INS and GPS (GNSS) ?
- What is the Kalman filter (KF), and how does it work?
 - You should understand the principles (and how the equations work).
- How does the KF compare to the least squares technique?
- Explain two simpler alternatives to the Kalman filter
 - Alpha filter
 - Complimentary filtering

Control systems

- Why is control so closely related to estimation ?
- Linear vs. nonlinear control
 - What can simple bang-bang (on/off) controllers be used for?
 - Why add hysteresis?
- Explain open loop vs. closed loop control
 - Be able to give at least one example of each
- Give an example of sequential control
- **PID control – explain !**
- Satellite control
 - What is detumbling ?
 - Can you explain the B-dot control law ?

Time and synchronization

- Why are time and synchronization important? Give some examples.
- What happens if the clock in the GPS receiver have an error of 1 ms relative to the atomic clocks in the GPS satellites?
- What can we do if we need an accurate crystal oscillators for our electronics?
 - Hint: OCXO vs TCXO vs CSAC
- Explain how the Computer clock (PC clock) works and its limitations
 - RTC
 - Software clock
 - Drift
- What do we mean with signal-based and time-based synchronization? Explain.

Time and synchronization II

- What is International Atomic Time (TAI)
- How is TAI related to UTC time ?
- Explain the use of Leap seconds
- What is GPS time ?
- Explain briefly different time codes/protocols that can be used for time and synchronization
 - IRIG-B
 - IEEE 1588 (PTP)
 - NTP
- Know roughly what kind of timing accuracy we can obtain with different technologies (time codes/protocols)
 - Seconds, ms, us or ns range.
 - Are they dependent on range/network complexity ?