Systems & Control Laboratory

http://www.halvorsen.blog

Hans-Petter Halvorsen
Table of Contents

1. **Introduction** – Course Overview
2. **What do you Learn?**
3. **Delivery/Submission**
   – **Quizzes** – Test your skills after each Lab Assignment
   – **Web Site** – Present your Work and Results after each Lab Assignment
4. **Lab Work Overview**
If you have knowledge of the standard pieces, and know how you can combine them, you can build everything.
Industries IT and Automation Topics

We will create Applications/Systems where we use these important topics:

- **Programming**
  - Software Engineering
  - Network
- **Database Systems**
- **Logging**
- **State Estimation**
- **System Identification**
- **Tools & Analysis**
  - Machine Learning
- **Control Systems**
  - PID, MPC
- **Data Acquisition**
  - Data Fusion
  - Smart Sensor
- **Modelling**
- **Industry**
- **Sensor Technology**
- **OPC**
- **Factory Automation**
- **Oil & Gas**
- **Home Automation**
- **Process Control**
- **Industry 4.0**
- **IoT**
- **IIoT**
- **Application Examples**:
  - Modelling
  - Control Systems
  - Monitoring
  - Data Fusion
  - Smart Sensor
  - Logging
  - Tools & Analysis
  - Machine Learning
  - Control Systems
  - PID, MPC
Focus on Next Generation Industry

We will learn the latest technology and terms used in the industry today and tomorrow.
Here you see different pieces from different Courses and Topics. What do you get when putting them together?

Can you solve the Puzzle?
Practical Approach (in form of Lab Work/Small Case Projects): We will create real-life Systems built from pieces already learned (theory) in other courses. You will see a greater picture, not only the small pieces
Systems and Control Laboratory

Theoretical Topics from other course:
- PID
- Simulations
- OPC
- State Estimation
- System Identification
- Industrial IT

“Put all the pieces together”

Explore Hardware, Software and Programming

“The Big Picture”

Implementation and Practical skills

Practical Problem Solving

Build Systems

Control Theory

Instrumentation

Data Communication

Modelling

Automation

Programming
1. Create Systems from smaller Pieces

2. Follow Instructions and use Examples, and previous knowledge from other courses as Foundation for your Work

3. Implement, Test and Document final System

4. Explore and Add Value
Building Systems

This course will be like playing with Lego. The instructions are only “half-finished”, the rest is up to you. Explore and be Creative!

We will create complete systems from smaller pieces that we put together.
Building Systems

We will create complete systems from smaller pieces that we put together.

Explore and be Creative!

Some of the pieces are “off the shelf”, others need to be “tailormade”, while some of them you might need to “make from scratch”. You may also need to use pieces that you have made previously (“reusable pieces”).

I have made lots of examples that you can use “as it is”, or better, use them as guidelines when creating your own pieces.

With that in mind, it may not be so time-consuming or difficult to make new Systems.

When creating these pieces you should always try to make them reusable.
Course Home Page

https://www.halvorsen.blog/documents/teaching/courses/syslab/

On this Web Site you find detailed information about the Course:

• Course Schedule
• Lab Assignments
• Hardware
• Software
• Videos
• Tutorials
• Code Examples
• etc.
What do you Learn?
Do you learn like this?

Traditional Lectures:

Passive Teaching with little Learning outcome
We will Create, Build, Implement, Test and Explore – and Collaborate!

In this course we will work with Practical Real-life Challenges
Building Systems

This course will be like playing with Lego. The instructions are only “half-finished”, the rest is up to you. Explore and be Creative!

We will create complete systems from smaller pieces that we put together. You should **get experience with practical problem solving** using theory, software, etc. you have learned in previous courses.
Main purpose with the course:

• **Get experience with practical problem solving** using theory, software, etc. you have learned in previous courses
• The learning will be through small practical case projects
• The teacher don't have all the answers/solutions to the problems, but he might have done something similar
• Use existing Theory and Practical Knowledge, existing Tutorials, Internet, etc. in order to solve the challenges
• The small projects are real life scenarios that you can expect to work in the Industry
Problem-based Learning (PBL)

This course will be based on Problem-based Learning principles. The focus is Practical Implementation.

The PBL students score higher than the students in traditional courses because of their learning competencies, problem solving, self-assessment techniques, data gathering, behavioral science, etc.

[The Polya Process]
Teaching Outcome

Lectures – 5%
Reading – 10%
Hear and See – 20%
Demonstrations – 30%
Discuss in Groups – 50%
Practical Exercises – 75%
Teaching others – 90%

Problem-based learning (PBL)

Passive Learning Principles

Active Teaching Principles

Student centric focus
Teaching Principles

1. **Problem based Learning (PBL):**
   - Less Theory
   - No Lectures in class
   - You should get experience with practical problem solving

2. **Flipped Classroom:**
   - No Lectures in class
   - You prepare for lab at home and get help and guidance in class
   - Individual help and adjustments
   - Collaborate with others, etc. in class
   - Go through Tutorials and Videos in advance
Course Contents

• We will work with traditional topics within Industrial IT and Automation
  – *Database Systems, DAQ, OPC, Sensors, Control Engineering, PID, Modelling, System Identification, State Estimation, MPC, etc.*

• In addition, we will put these topics in a wider concept and see how these traditional topics can be applied to and used within concepts like
  – *Industry 4.0, Internet of Things (IoT), Cloud Computing, Machine Learning, Smart Technology, Web Technology, etc.*
Course Contents

• The course contains Practical Lab Work within Industrial IT and Automation Topics.

• There will be no ordinary lectures, only Practical Lab Work. The theory in the course is based on the theory you have already learned in other courses.

• There will be 3 different Labs (4-5 weeks for each lab)

• The contents may vary from year to year
Main Goals with this Course

- **Create Systems** built from pieces already learned, see a greater picture, not only the small pieces. **Make stuff from scratch.**
- **Explore Hardware, Software and Programming Languages**
- Get **Practical Skills** combining Hardware and Software
- **Apply Theory** (learned in other courses) in Practical Applications
- In general, Practical **Problem Solving**!
- “**Make Things Work**”
- Become a “**Master of Science**”
- **Prepare** for upcoming **Work in Industry**, or similar Work
- The small projects are **Real-life Scenarios** that you can expect to work in the Industry
- Know about and learn Todays Technology and **Technology of Tomorrow**
Delivery/Submission
Delivery/Submission

- **Quizzes**: For each of the Lab Assignments you need to submit a Quiz. The Quizzes test your acquired skills within the topics covered in the Lab Assignments.

- **Web Site**: You need to present your Work done in each of the Lab Assignments in a Web Site created by you.
  - The overall systems, not all tiny details!
Quizzes

• Test your acquired skills within the topics covered in the Lab Assignments
• The Questions should be easy to answer if you have worked properly with the Lab Assignments
• Multiple Choice Questions
• The Quizzes will automatically set a score between 0-100%
• You need to have more than 70% correct answers to pass the Quiz.
Web Site

Take Digitalization one step further

– We build a Web Site instead of writing a standard technical report as PDF
We shall create a Web Site (HTML, CSS, PHP, ...) where you present your work

- You need to know basic **HTML**, CSS, (PHP, MySQL). A good source to this knowledge is: [https://www.w3schools.com](https://www.w3schools.com)
- Recommended HTML Editor: **Visual Studio Code** (or you can use Visual Studio, but VS is not well suited for HTML pages)
- We will use the available Web Servers at the University. The Web address (URL) will be like this: [https://web01.usn.no/~username](https://web01.usn.no/~username) (typically a 6 digits number)

**Resources:**

- [https://min.usn.no/egne-nettsider/webomrade-pa-linuxplattform-article211832-32619.html](https://min.usn.no/egne-nettsider/webomrade-pa-linuxplattform-article211832-32619.html)
Web Server  - https://web01.usn.no

Server-side

Apache

HTTP SERVER

HTML

CSS

Internet

Clients

PCs with Web Browsers

HTML

HTML

Popcorn

PHP

Web Server

PCs with Web Browsers
Web Server - https://web01.usn.no

- Server:
  - Operating System: Linux
  - Web Server: Apache
  - Database: MySQL
  - Supported Languages: HTML, CSS, PHP
- Web Address: https://web01.usn.no/~username
- UserName = Student Number (typically a 6 digits number)
- Allowed Start Pages:
  - index.html, index.php
- FTP: WinSCP, FileZilla or similar
HTML

Good Resource for creating Web Pages with HTML, CSS, JavaScript, SQL, PHP, etc.

http://www.w3schools.com

HTML: https://www.w3schools.com/html/
CSS: https://www.w3schools.com/css/
PHP: https://www.w3schools.com/php/
Lab Work Overview
3 Lab Assignments

• Industry 4.0 and Automation
• Internet of Things (IoT) Control System
• Machine Learning in Automation Systems

Focus: Practical Implementation and Examples – not advanced Theory (which you have learned in other courses)

Note!
The Lab Assignments may vary from year to year, both the number, the titles and the contents
Lab Work

• Always meet well prepared!
  – Read the Assignment in detail and start Planning your work before you meet in the Laboratory
  – Install necessary Software, etc. before you meet in the Laboratory

• Not hurry up to finish as fast as possible!

• Play and Explore!

• Be Curious!

• Add Value!

Just don't copy the Examples! Make it from scratch in your own way! You need to understand what's happens! Play and Explore! Add Value to your code!

Anyone can follow a recipe (the assignment), but not everyone becomes a chef. Try to figure out how you become a chef!
Hardware

- Arduino
- Multimeter
- Router
- Network Equipment
- PC
- DAQ Hardware
- Sensors
- Small-scale Industrial Processes
- PID
- Air Heater: Small-scale Process
- Level Tank: Small-scale Process
- Tools
Most of the Software will be known from other Courses

+ Different specialized Software (OPC, ...)

The University has Site License

Available for Free with Microsoft Imagine
Lab Gathering

• Purpose: Finishing the Lab Assignments using available Hardware in the Laboratory (Room: C-222)
• Activities: Self-paced work in the Laboratory
• It is important that you do as much as possible in advance! - otherwise you will be very busy at the Lab Gathering!
• The Lab Gathering is compulsory
Lab 1

Industry 4.0 and Automation
Lab 1: Industry 4.0 and Automation

- Control Design in MATLAB, Frequency Response, etc.
- Implementing Next Generation Control System/SCADA System in LabVIEW (or C#)
- OPC UA – The Industry 4.0 Implementation of OPC
- Cloud-based Datalogging (IoT/IIoT)
  - SQL Server stored in Microsoft Azure
- Monitoring and Analysis in the Cloud
  - Web-based (ASP.NET/C#) system hosted at Microsoft Azure
The 4. Industrial Revolution – Data Power and the Internet have made it possible

**Industry 4.0**

IoT, Digitalization, Self-learning Algorithms, Robots and Big Data Analysis will over the next 10 years change the whole industry.

1. Water, Steam and Mechanical production
2. Electricity and mass production
3. Electronics, IT and Automation
4. Cloud

**Historical Timeline**
- 20 mill Years ago: First mankind
- Year Zero
- ~1784
- ~1870
- ~1969
- ~2011->

**First Industrial Revolution**
- Water, Steam and Mechanical production

**Second Industrial Revolution**
- Electricity and mass production

**Third Industrial Revolution**
- Electronics, IT and Automation

**Fourth Industrial Revolution**
- Data Power and the Internet
Industry 4.0

More Intelligent Systems

- Big Data
- Web Technology
- Machine Learning
- Cloud

Industry 4.0

- Industrial IT
- Automation
- Control Engineering
- OPC
- IoT
- Mobile Technology

All devices are connected to Internet

"Industry 3.0"

Data Analysis: These algorithms work with large amounts of data ("Big Data") in order to make intelligent decisions and predictions.

Its all about intelligent algorithms and models implemented in a computer, either locally or in the cloud, so-called Cloud Computing.
Purpose with Air Heater: Control the Temperature on the outflow

Air flowing through the tube

Air Heater

Heating Element

Fan

Air

Small-scale Laboratory Process

Warm Air

Temperature

Control heat (0-5V)

Temperature1 (1-5V)

Temperature2 (1-5V)

Fan Speed Indicator (2.3-5V)

Fan Speed Adjust
USB-6008 I/O Module

USB based I/O Module which is connected to your PC
Basic Control System

PC

I/O Module

USB-6008

SCADA System

LabVIEW or C#

Analog In (Temperature)

Analog Out (Control System)

Air Heater

Process
Industry 4.0 and Automation

Practical Implementation of Next generation Automation/SCADA Systems

The Industry 4.0 Implementation of OPC

Control System/SCADA

PC with Control Application

PID Controller
Lowpass Filter
 Scaling

Process Value

Digital Signal

USB-6008 DAQ

D/A

0~5V

Control Signal u

Frequency Response

1~5V

T_{out}

Air Heater Process

AO

Analog Measurement

Temperature

Temperature

USB-6008 DAQ

LabVIEW

Microsoft SQL Server

Windows Azure

Cloud Storage and Analysis

Cloud-based Datalogging

ASP.NET

Web Application

Monitoring and Analysis

MATLAB

Visual Studio
Example: Cloud based Monitoring Web Application created with ASP.NET

Created by one of the students

```
From: 15/11/2017 13:45
To: 15/11/2017 14:15
```
Lab 2
Internet of Things (IoT) Control System
Lab 2: Internet of Things (IoT) Control System

- Create an **Embedded PID Controller using Arduino**
  - Challenge: Arduino UNO has no Analog Out
- **HIL Simulations and Testing**
  - Test the Embedded System on a Simulator before you apply it on the real process
- **Remote Access and Cloud-based Publishing of Data**
  - ThingSpeak. ThingSpeak is a free Cloud Service (using REST APIs) that lets you collect and store sensor data in the cloud and develop Internet of Things applications
Internet of Things (IoT)

Soon everything will be connected to the Internet – even your Coffee Maker

Industrial Internet of Things (IIoT) is another word for Industry 4.0

IoT – Consumer oriented, Smart Home Solutions, etc.

IIoT – Industrial use of IoT Technology.
Arduino is an open-source electronics platform.
Controlling the Air Heater using Arduino

Embedded PID Controller

PC as Controller

Air Heater (Process)

Industrial PID Controller

PV

MV
Internet of Things (IoT) Control System
Practical Implementation of IoT, Cloud Computing, and Embedded Systems

- Arduino IDE
- Download your Application and then remove USB cable
- Embedded Arduino PID Controller
- Control System
- Feedback System
- ThingSpeak Cloud
- Cloud-based Publishing of Data
- Compare with commercial PID
- Cloud - based Publishing of Data
- Air Heater
- Test first using HIL Simulation and Testing
- Arduino
- DAC
- Breadboard
- Analog In
- Banana Connector
- $y$
- $K_p, T_i, T_d, r$
- Analog Out
- Banana Connector
- $u$
- $y$
- Compare with commercial PID
- Practical Implementation of IoT, Cloud Computing, and Embedded Systems
Embedded Arduino PID Example

For a “professional” look, you may put your embedded PID in a box/case like this:

The box can have Female Banana Plugs for easy connection of the Embedded Controller to the Air Heater Process

Created by a previous student
Lab 3

Machine Learning in Automation Systems
Lab 3: Machine Learning in Automation Systems

• **Machine Learning**
  – ML is all about intelligent algorithms implemented in a computer, either locally or in the cloud, so-called Cloud Computing.
  – These algorithms work with large amounts of data ("Big Data") in order to make intelligent decisions.

• We will use traditional Machine Learning principles known from Automation, such as:
  – **System Identification** (*Least Square, Sub-space methods, ...*)
  – **State Estimation with Kalman Filter**
  – and **Model Predictive Control (MPC)** - and see how these techniques can be seen in the wider concept of Machine Learning.
Machine Learning

A simplified sketch of the Machine Learning process:

- **Big Data**
  - Data
  - Data Preparations
  - Iterative

- **Cloud**
- **Model**

The goal is to understand the structure of the data and find patterns.

Statistics Analysis

Model Validation

Algorithms
Level Tank System

Purpose: Control the Level in the Water Tank
We will apply traditional Machine Learning principles used in Automation Systems such as System identification, Kalman Filter and MPC.
LabVIEW Example (PID + Kalman + FF)

This is just a “bad” example – try to create a better application.
Are you a Chef?

• Anyone can follow a recipe (the assignments with examples), but not everyone becomes a Chef.
• What is needed to make an extraordinary good meal?
• A Chef adds spices and secret ingredients - and presents it in a delicate way
• A Chef works hard and targeted. He experiments with new concepts. He “Think outside the Box”. Etc.
• Try to figure out how you become a Chef!
“Make it as simple as possible, but not simpler.”
Albert Einstein

“Programming is both Science and Art”
– Programming is Engineering