Systems & Control Laboratory

http://www.halvorsen.blog

Hans-Petter Halvorsen

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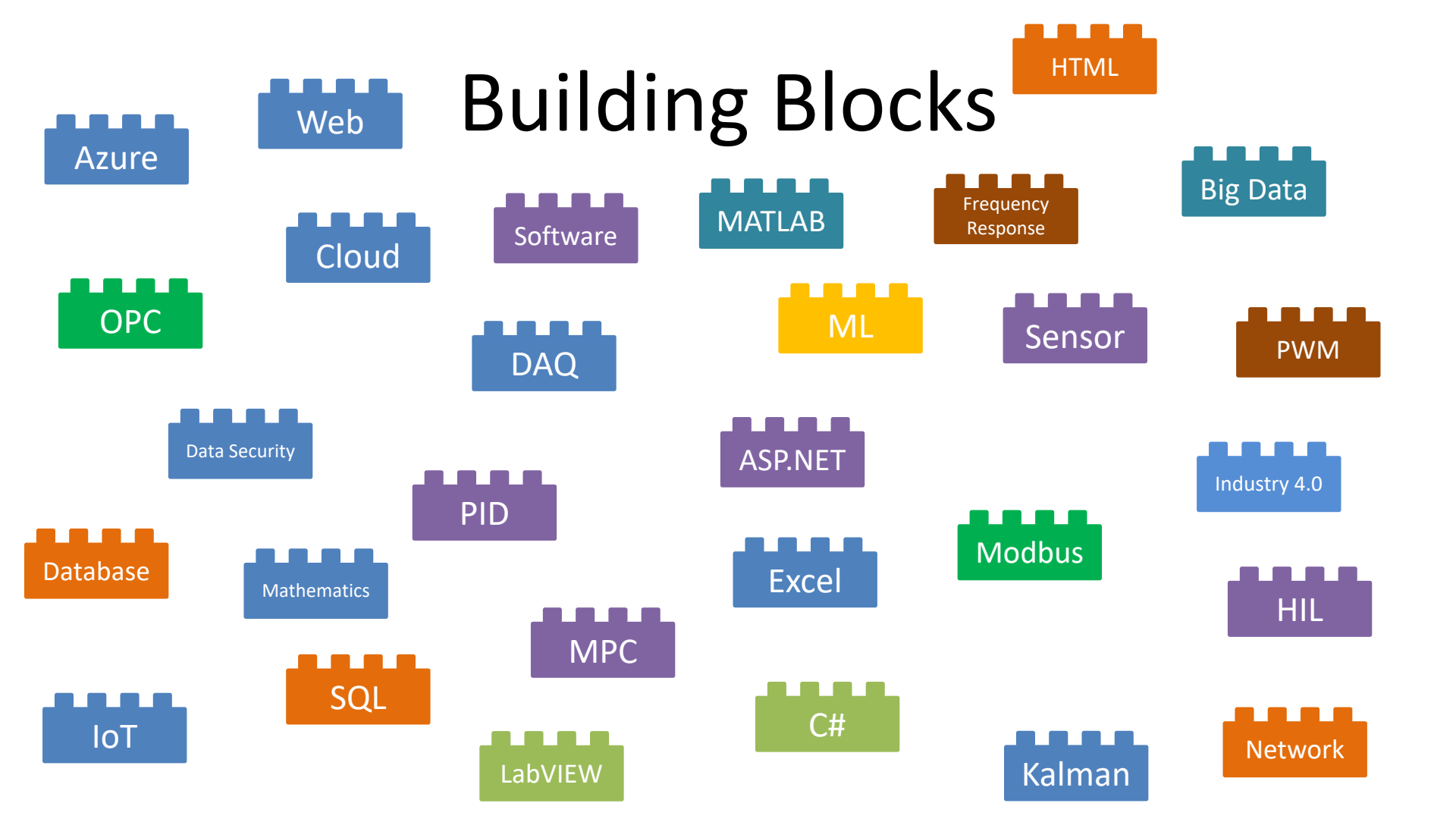
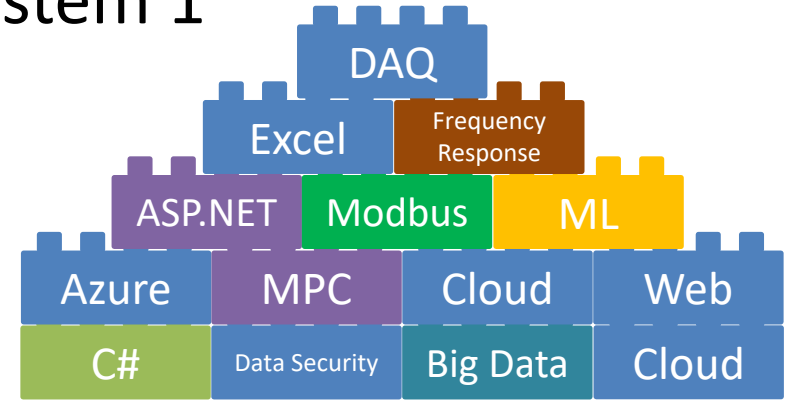
Building Blocks

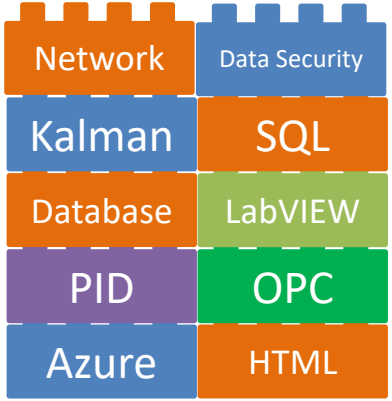


Building Systems

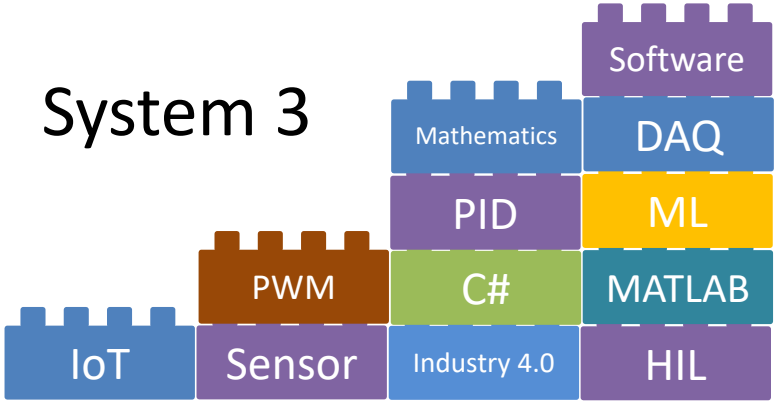
System 1



System 2



System 3



If you have knowledge of the standard pieces, and know how you can combine them, you can build everything

Industrial IT and Automation Topics

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

Industry

OPC

Industrial IT

Programming

Software Engineering

Network

Database Systems

Logging

Data Fusion

Smart Sensor

Tools & Analysis

Sensor Technology

Data Acquisition

State Estimation

System Identification

Modelling

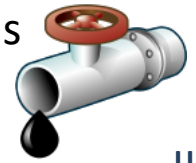
Application Examples:

Industry 4.0

Factory Automation

Process Control

Oil & Gas



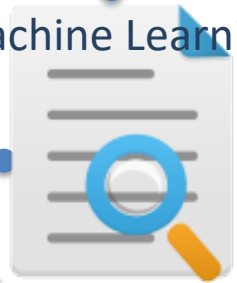
Home Automation

IoT

IIoT

Control Systems

PID, MPC

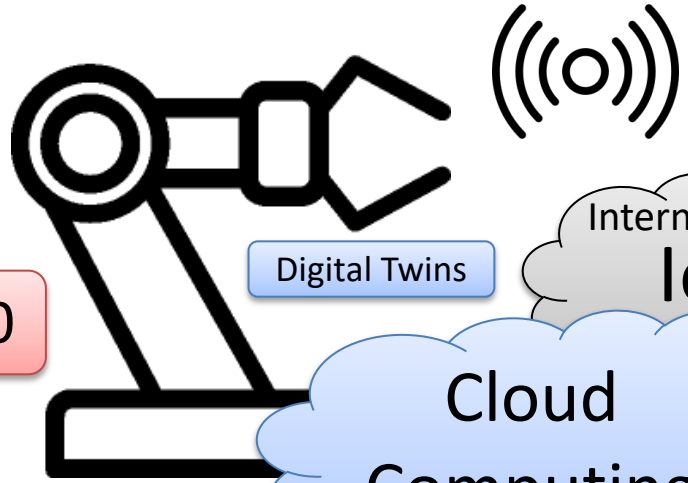


Machine Learning

Monitoring

Focus on Next Generation Industry

We will learn the latest technology and terms used in the industry today and tomorrow



Big Data

Internet of Things

IoT

Digital Twins

Industry 4.0

AI

IIoT

Industrial Internet of Things

Cloud Computing

Machine Learning

Mobile and Web Technology

OPC UA™

Digitalization

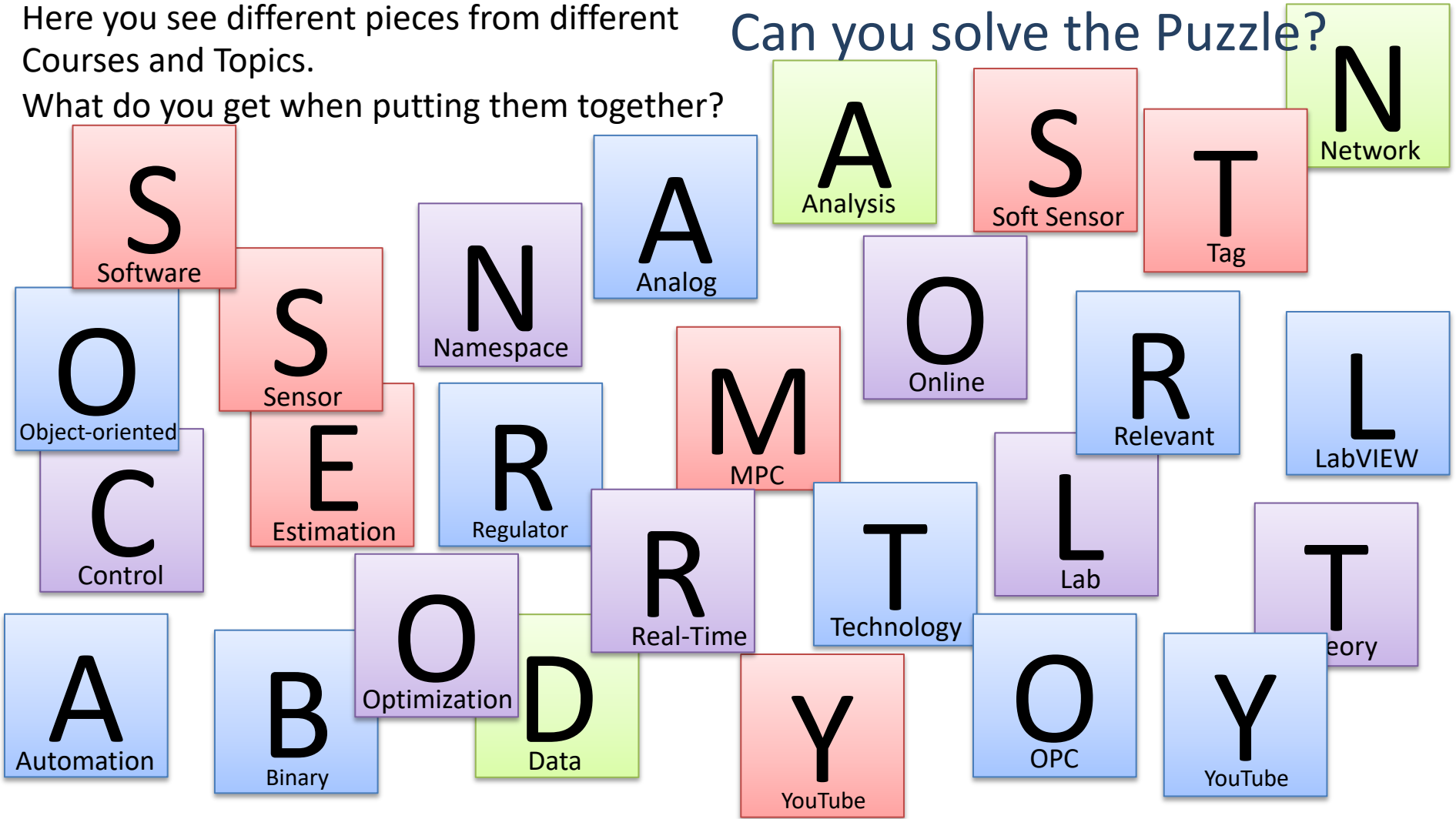
Cyber Security

Software Engineering

Here you see different pieces from different Courses and Topics.

What do you get when putting them together?

Can you solve the Puzzle?



S Software	Y YouTube	S Sensor	T Tag	E Estimation	M MPC	S Soft Sensor	A Analysis	N Network
D Data	C Control	O Optimization	N Namespace	T Theory	R Real-Time	O Online	L Lab	L LabVIEW
A Automation	B Binary	O Object-oriented	R Regulator	A Analog	T Technology	O OPC	R Relevant	Y YouTube

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:

Industrial IT

OPC

State Estimation

System Identification

Simulations

PID

Modelling

Programming

Automation

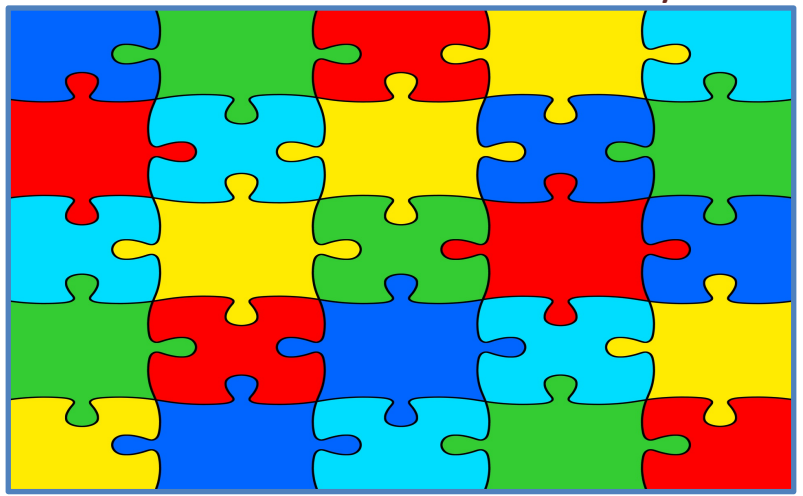
Control Theory

Instrumentation

Data Communication

Explore Hardware, Software and Programming

Build Systems

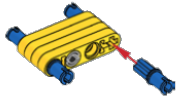


"The Big Picture"

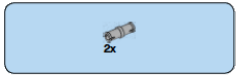
Put all the pieces together

Implementation and Practical skills

Practical Problem Solving



1. Create Systems from smaller Pieces



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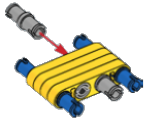
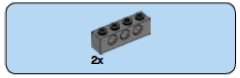
2. Follow Instructions and use Examples, and previous knowledge from other courses as Foundation for your Work





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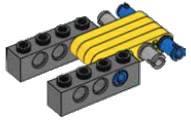

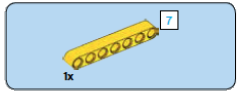

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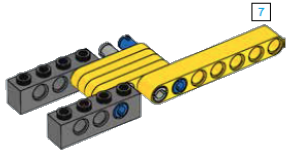
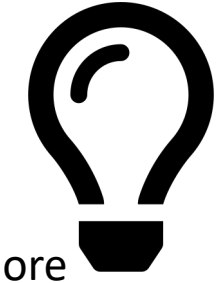
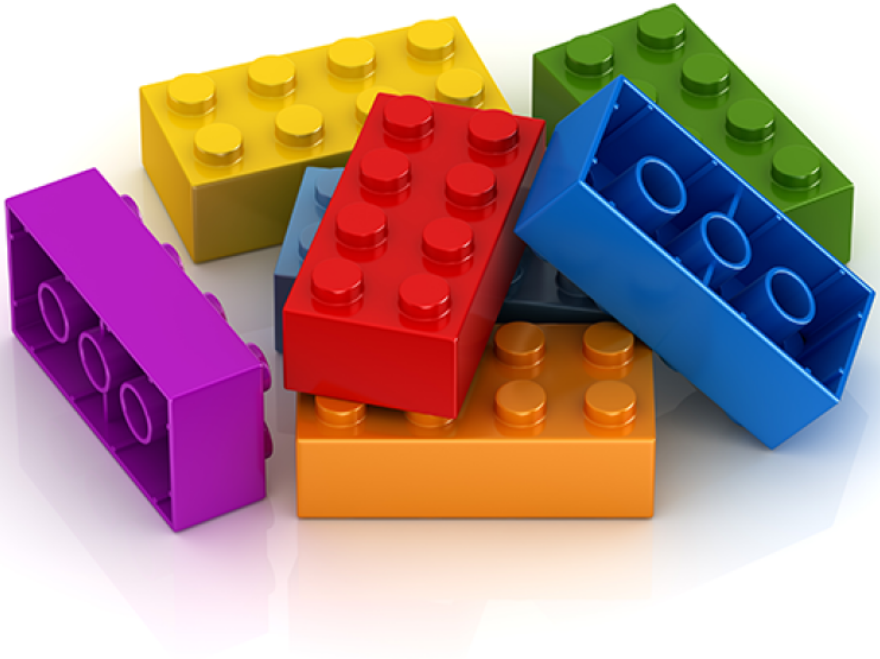


3. Implement, Test and Document final System



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!

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

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”).

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/

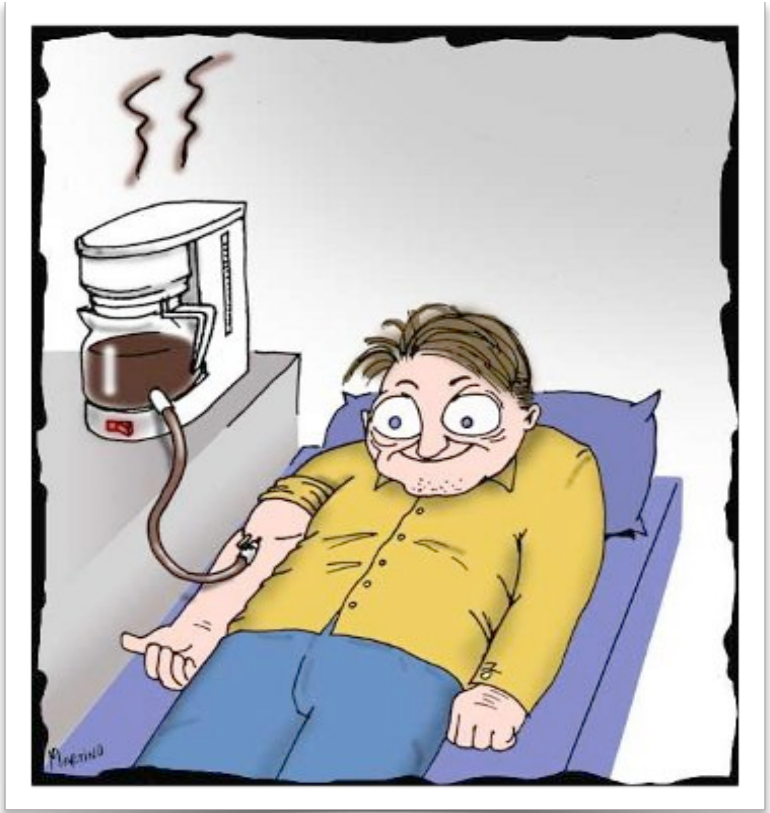
On this Web Site you find detailed information about the Course:

- Course Schedule
- Lab Assignments
- Hardware
- Software
- Videos
- Tutorials
- Code Examples
- etc.

What do you Learn?

Do you learn like this?

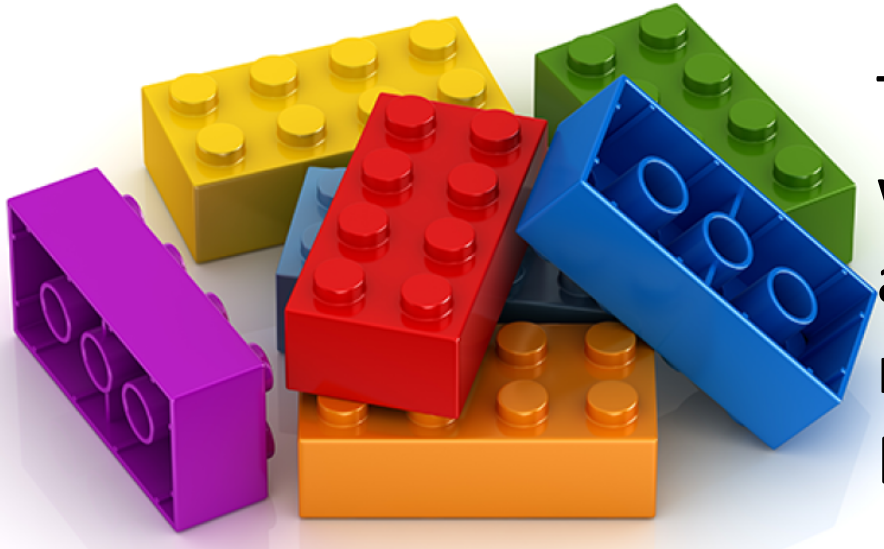
Traditional Lectures:



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.

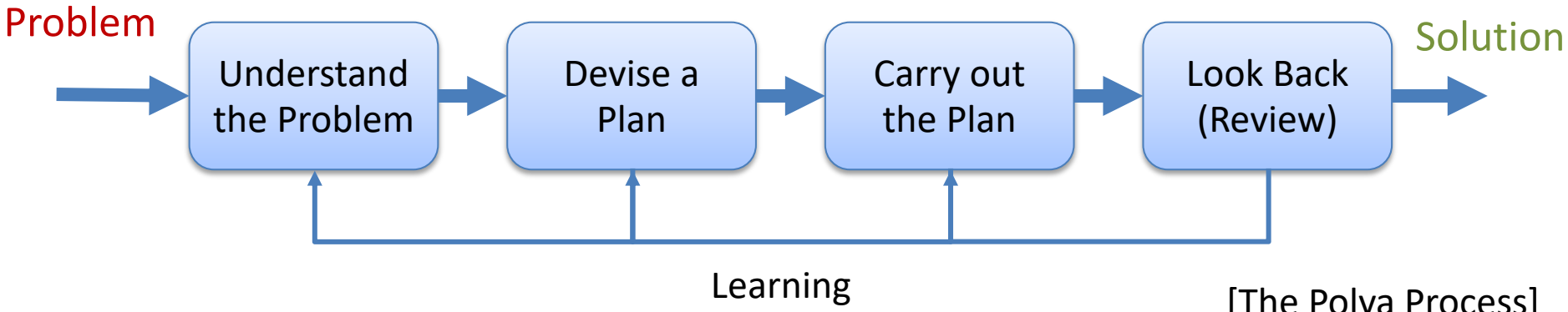
Systems & Control Laboratory

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 Polya Process]

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.

Teaching Outcome

Lectures – 5%

Reading– 10%

Hear and See – 20%

Demonstrations – 30%

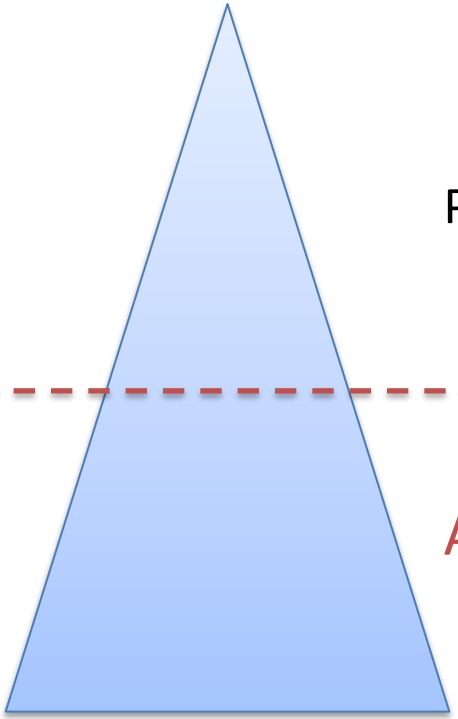
Passive Learning Principles

Discuss in Groups – 50%

Practical Exercises – 75%

Teaching others – 90%

Active Teaching Principles



Problem-based learning (PBL)

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

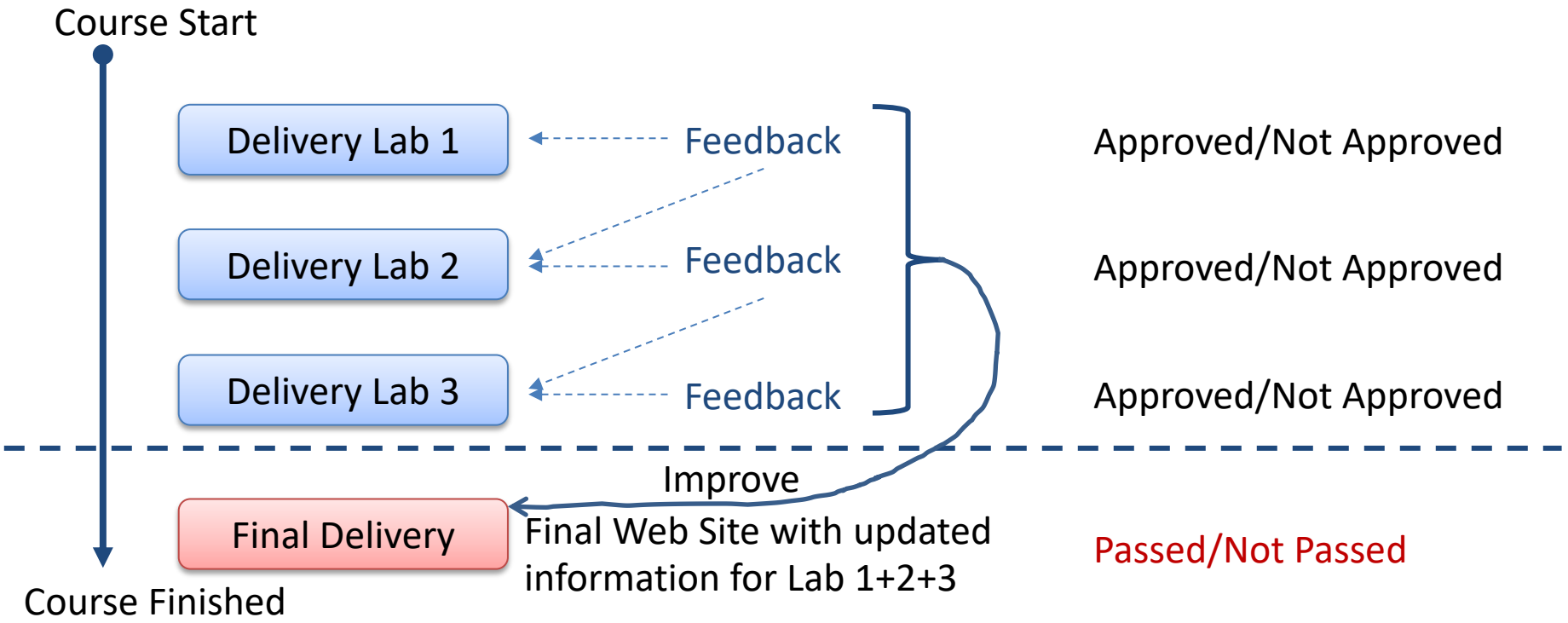
- **Create Systems** built from pieces already learned, see a greater picture, not only the small pieces. **Make stuff from scratch**.
- **Explore Hardware**, **Software** and **Programming** Languages
- Get **Practical Skills** combining Hardware and Software
- **Apply Theory** (learned in other courses) 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!

Delivery/Submission



Quizzes

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

Web Site

- 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
- 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 (typicallly a 6 digits number)

Resources:

- https://min.usn.no/egne-nettsider/webomrade-pa-linuxplattform-article211832-32619.html

Web Server - https://web01.usn.no

Server-side

HTML

CSS

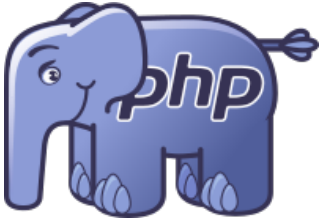
Internet

Clients

PCs with Web Browsers

Apache

HTTP SERVER



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 (typicallly a 6 digits number)
- Allowed Start Pages:
  - index.html, index.php
- FTP: WinSCP, FileZilla or similiar

w3schools.com

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

4-5 Weeks on each Lab

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

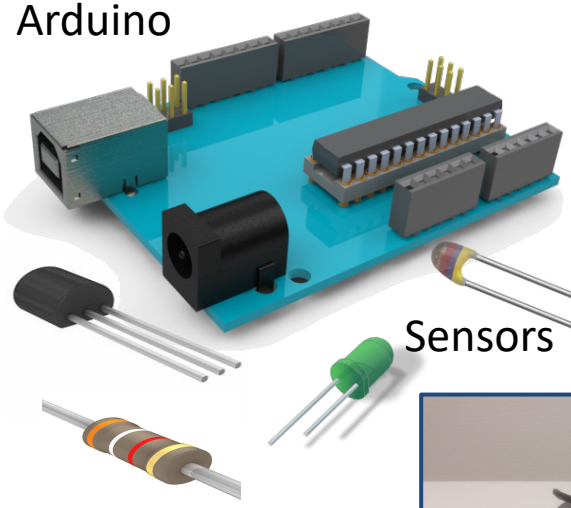
Just don't copy the Examples! Make it from scratch in your own way! You need to understand what's happens! Play and Explore! Add Value to your code!

- 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!

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

Hardware

Arduino

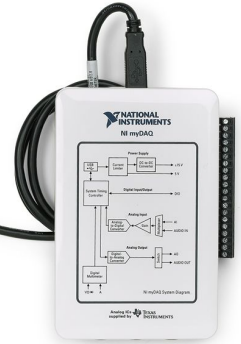


Sensors

Router

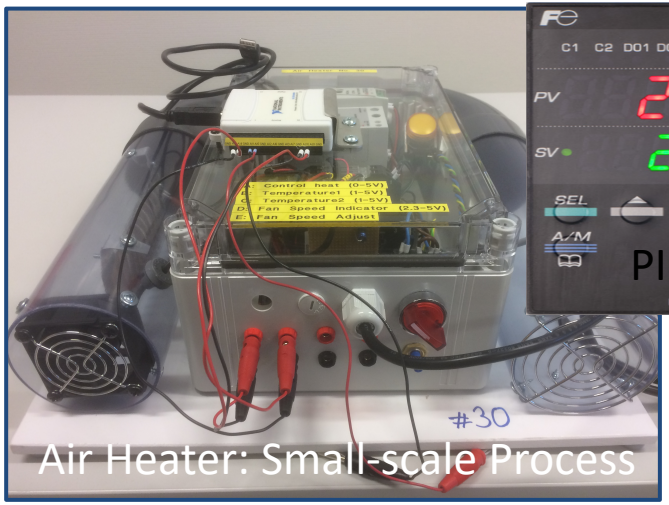
Network Equipment

PC



DAQ Hardware

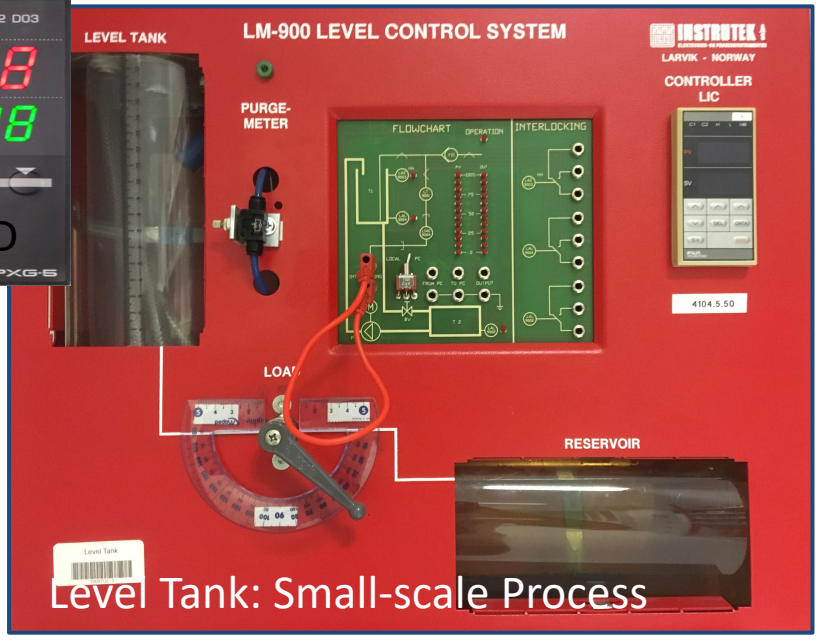
Small-scale Industrial Processes



Air Heater: Small-scale Process

Multimeter

Tools



Level Tank: Small-scale Process

Software

NATIONAL INSTRUMENTS LabVIEW™

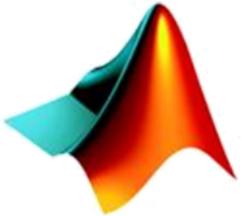
The University has Site License

ThingSpeak

Microsoft® SQL Server®

erwin

ARDUINO



MATLAB

The University has Site License

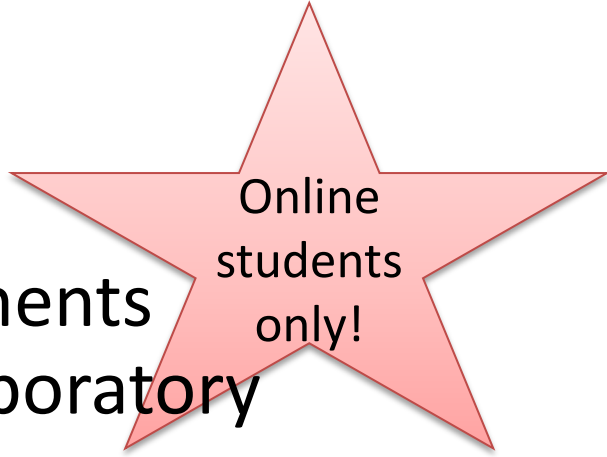
Visual Studio C#

Available for Free with Microsoft Imagine

+ Different specialized Software (OPC, ...)

Most of the Software will be known from other Courses

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

Cloud

Internet of Things

4

Industry 3.0

Industry 4.0

Robotics

1 Water, Steam and Mechanical production

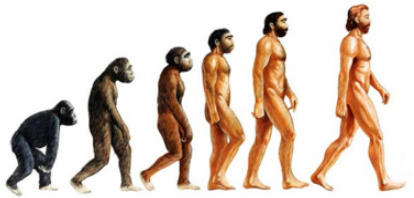
Industry 2.0

Industry 1.0

CPU

3

Electronics, IT and Automation



2 Electricity and mass production

Today

20 mill Years ago

First mankind

Year Zero

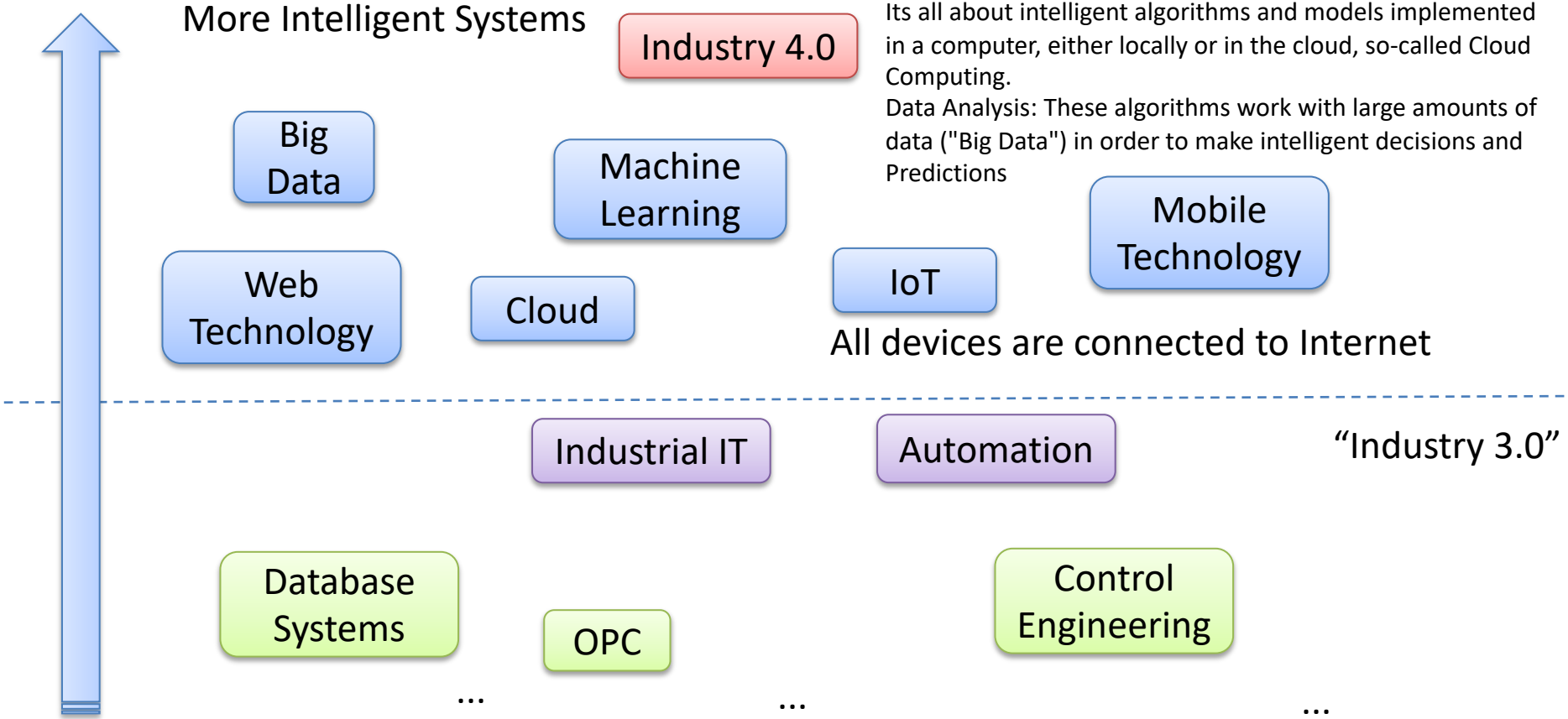
~1784

~1870

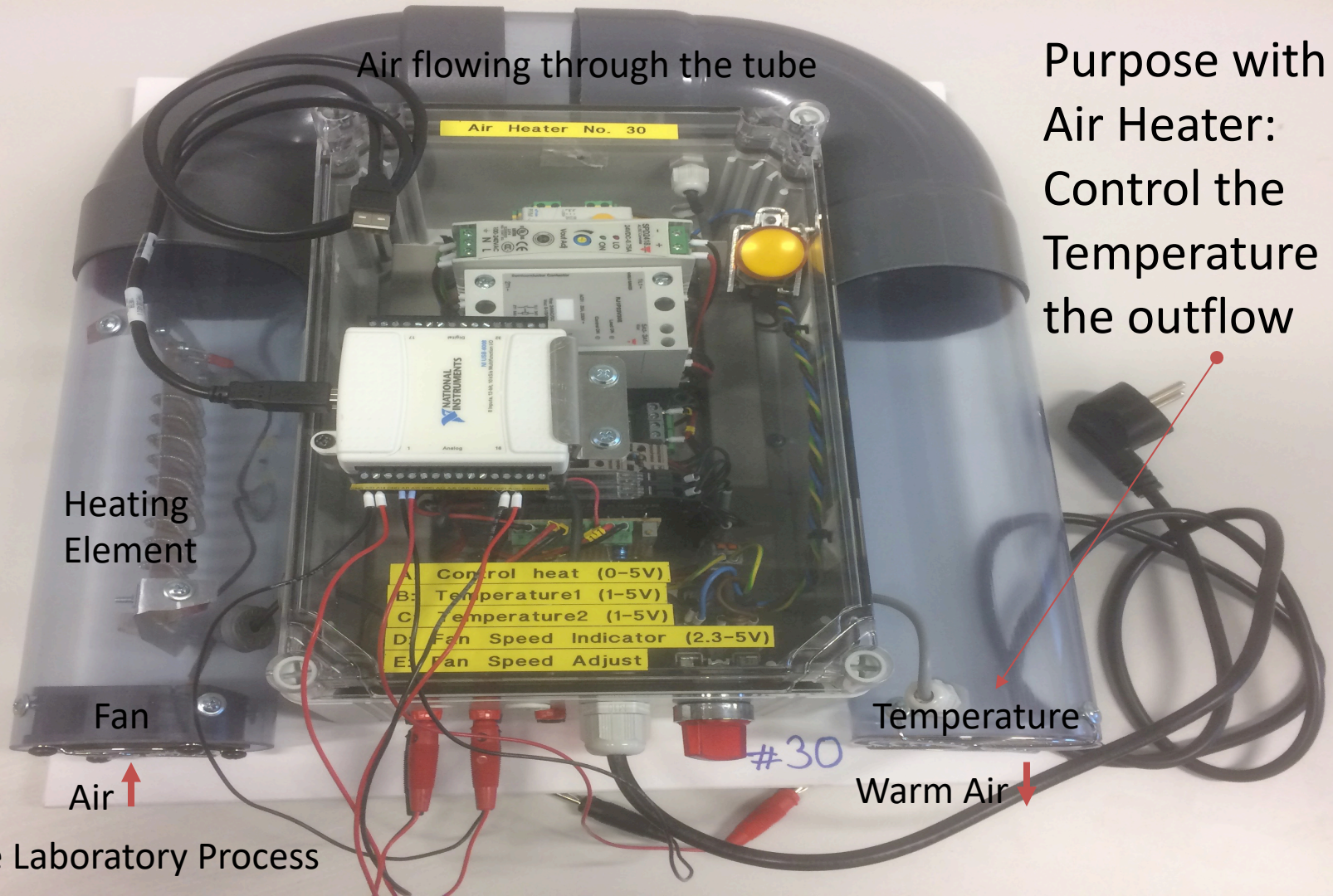
~1969

~2011->

Industry 4.0


More Intelligent Systems
Industry 4.0
Its all about intelligent algorithms and models implemented in a computer, either locally or in the cloud, so-called Cloud Computing.
Data Analysis: These algorithms work with large amounts of data ("Big Data") in order to make intelligent decisions and Predictions
Big Data
Machine Learning
Mobile Technology
Web Technology
Cloud
IoT
All devices are connected to Internet
Industrial IT
Automation
“Industry 3.0”
Database Systems
OPC
Control Engineering
...
...
...

Air Heater

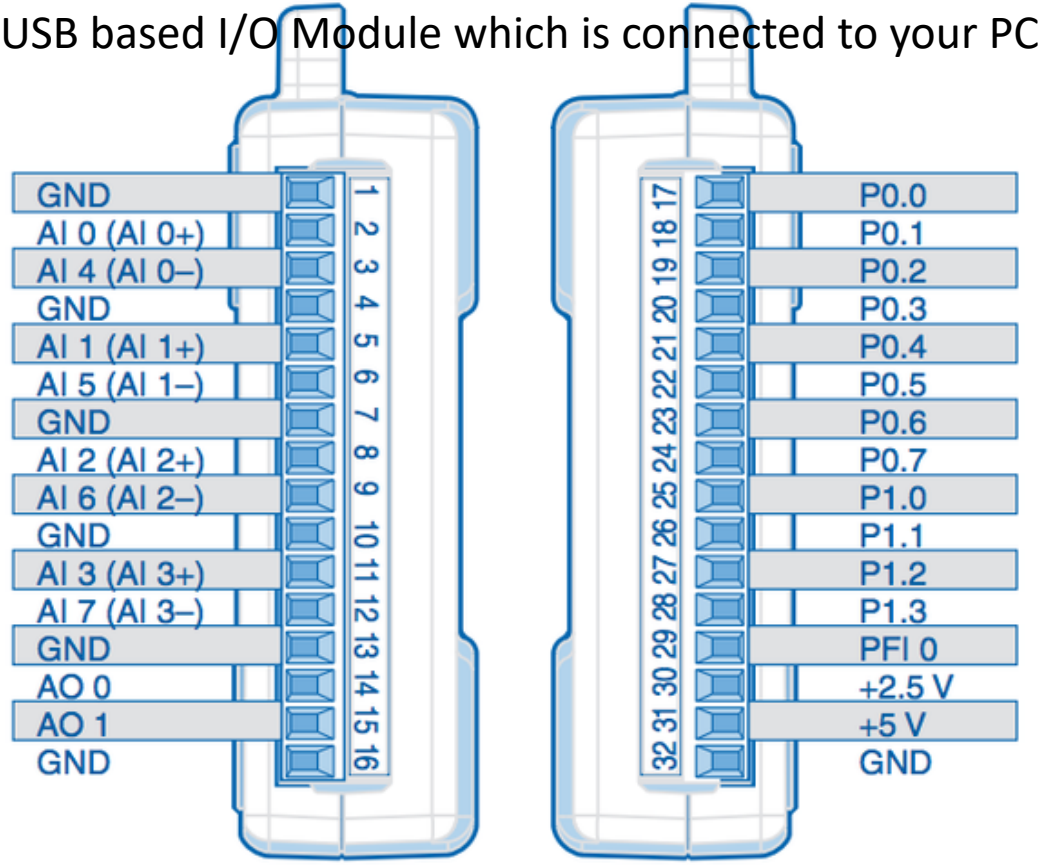


Purpose with Air Heater: Control the Temperature on the outflow

Small-scale Laboratory Process

USB-6008 I/O Module

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

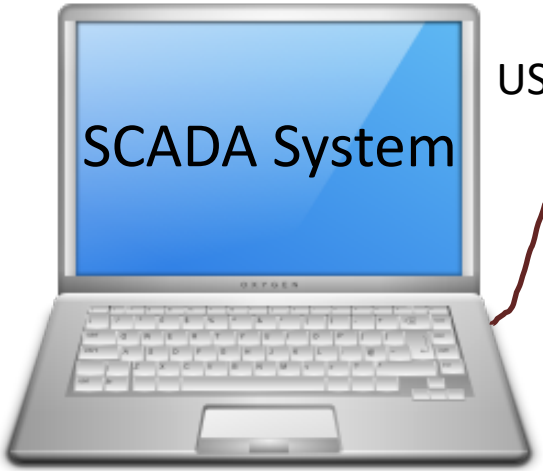


Basic Control System

PC

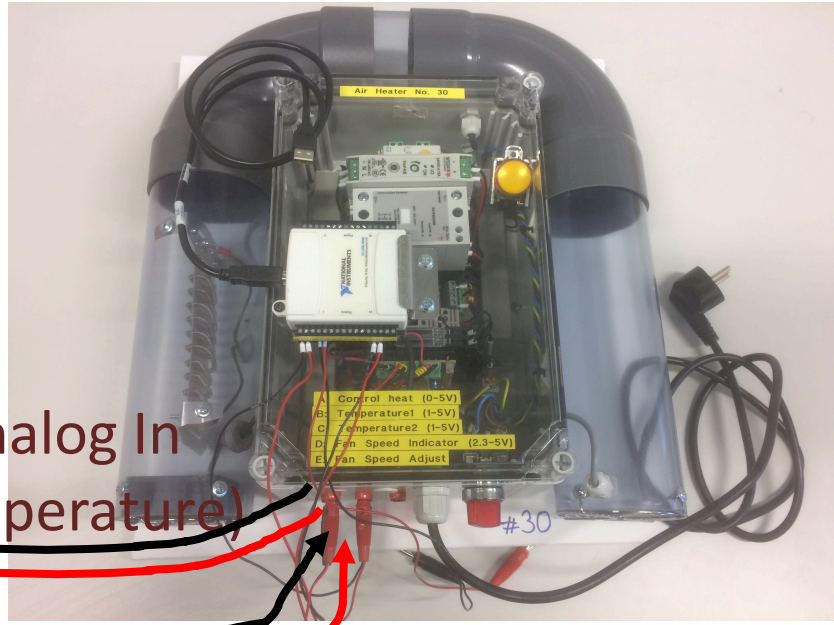
I/O Module

Process



USB

USB-6008



Analog In (Temperature)

LabVIEW or C#

Analog Out (Control System)

Air Heater

Industry 4.0 and Automation

Practical Implementation of **Next generation** Automation/**SCADA** Systems

OPC UA™

The Industry 4.0 Implementation of OPC

Microsoft® SQL Server®

SQL Server

erwin

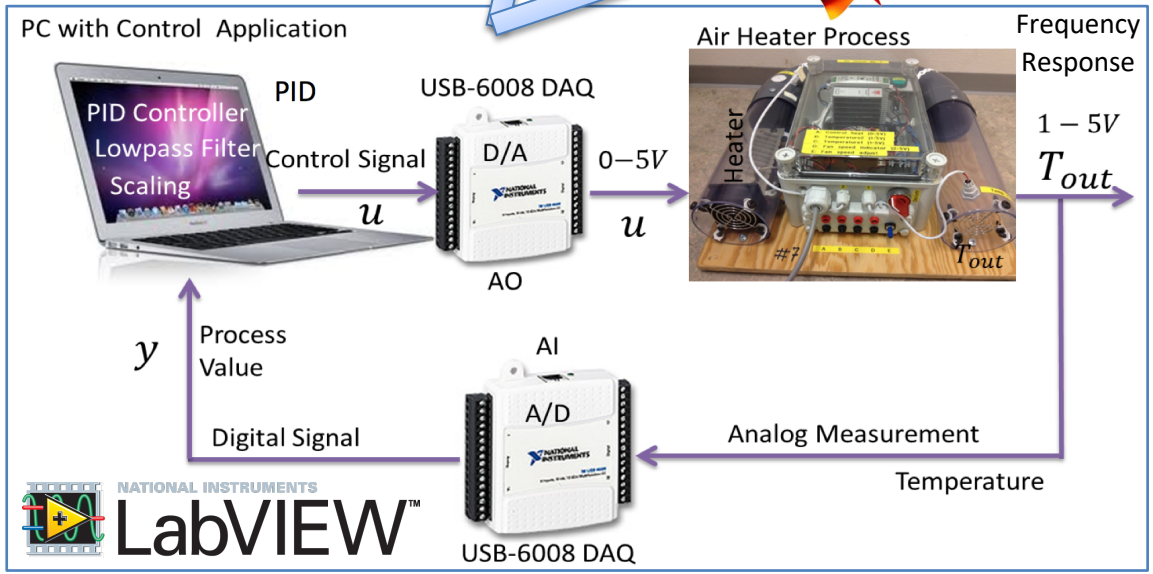
Windows Azure

Cloud Storage and Analysis

Cloud-based Datalogging

Control System/**SCADA**

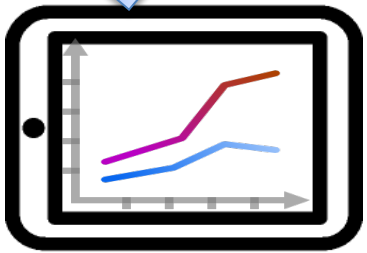
MATLAB



Visual Studio

ASP.NET

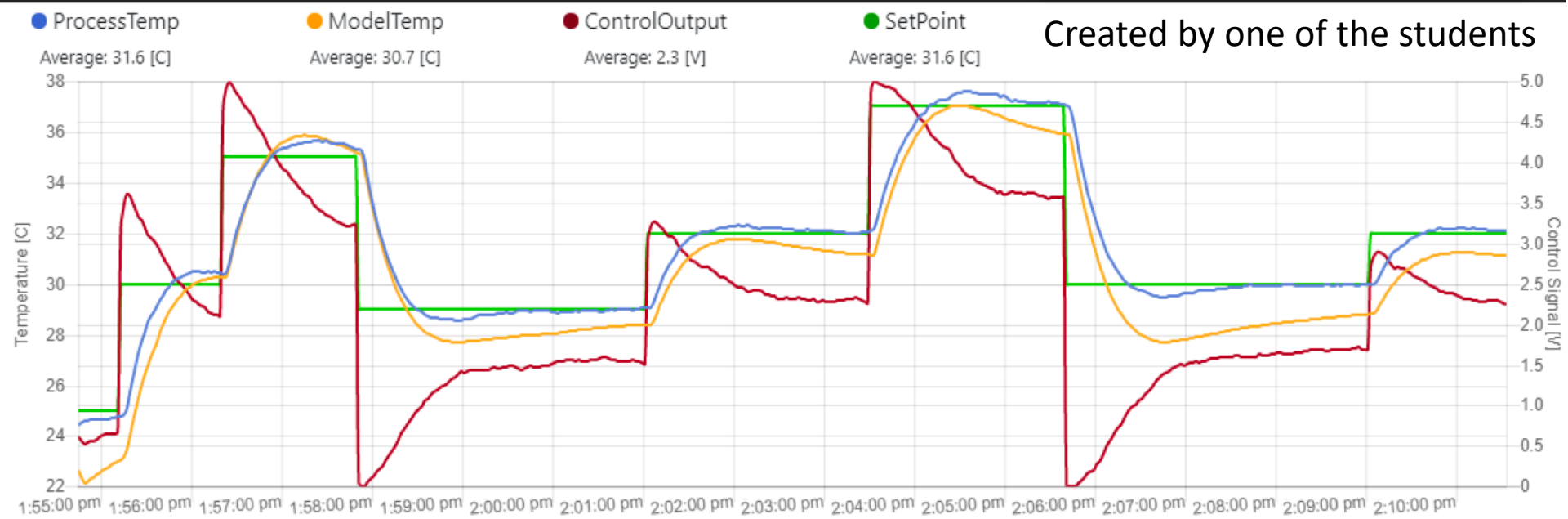
Web Application



Monitoring and Analysis

Air Heater Monitoring

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



Created by one of the students

Created by one of the students

From:

15/11/2017 13:45

To:

15/11/2017 14:15

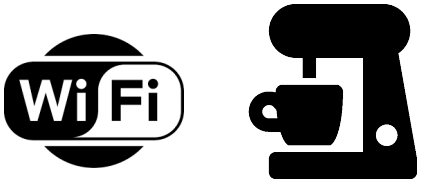
Lab 2

Internet of Things (IoT) Control System

Lab 2: **Internet of Things (IoT)** Control System

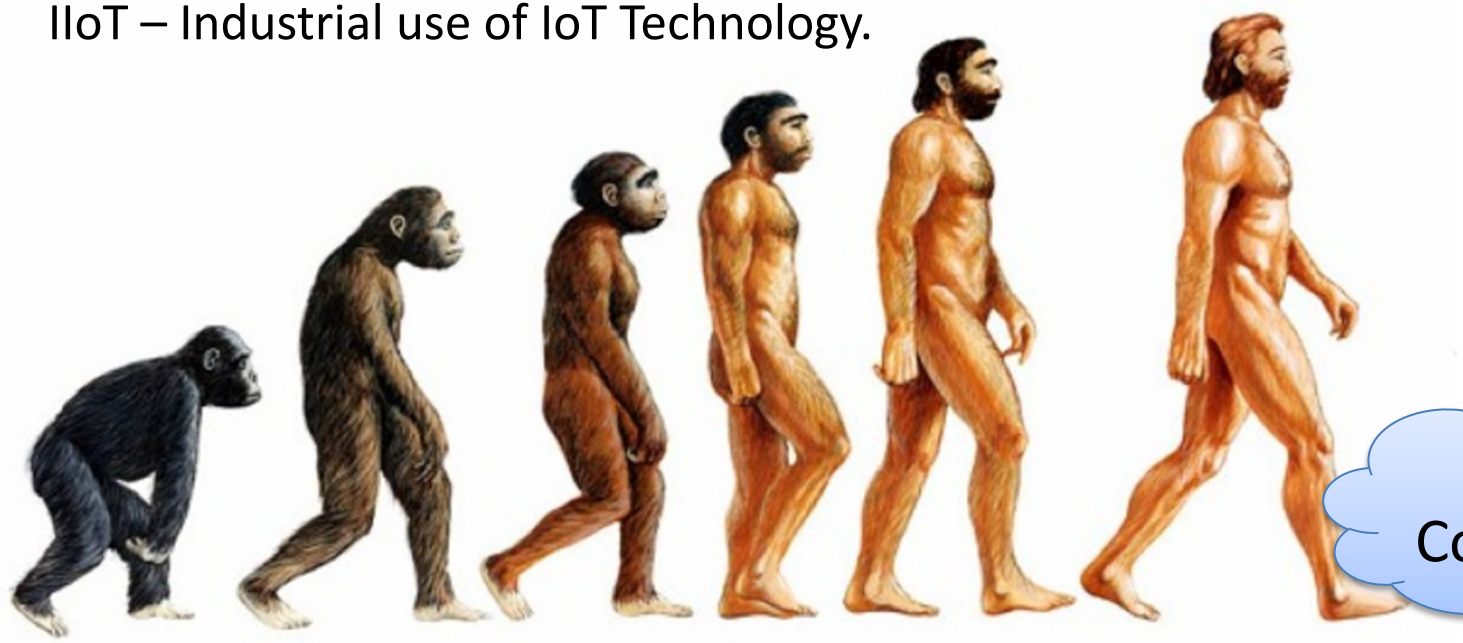
- Create an Embedded PID Controller using Arduino
  - Challenge: Arduino UNO has no Analog Out
- HIL Simulations and Testing
  - Test the Embedded System on a Simulator before you apply it on the real process
- Remote Access and Cloud-based Publishing of Data
  - ThingSpeak. ThingSpeak is a free Cloud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

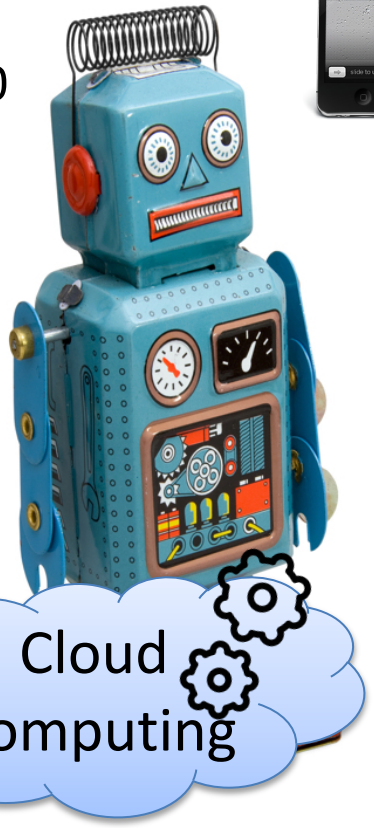
Internet of Things (IoT)



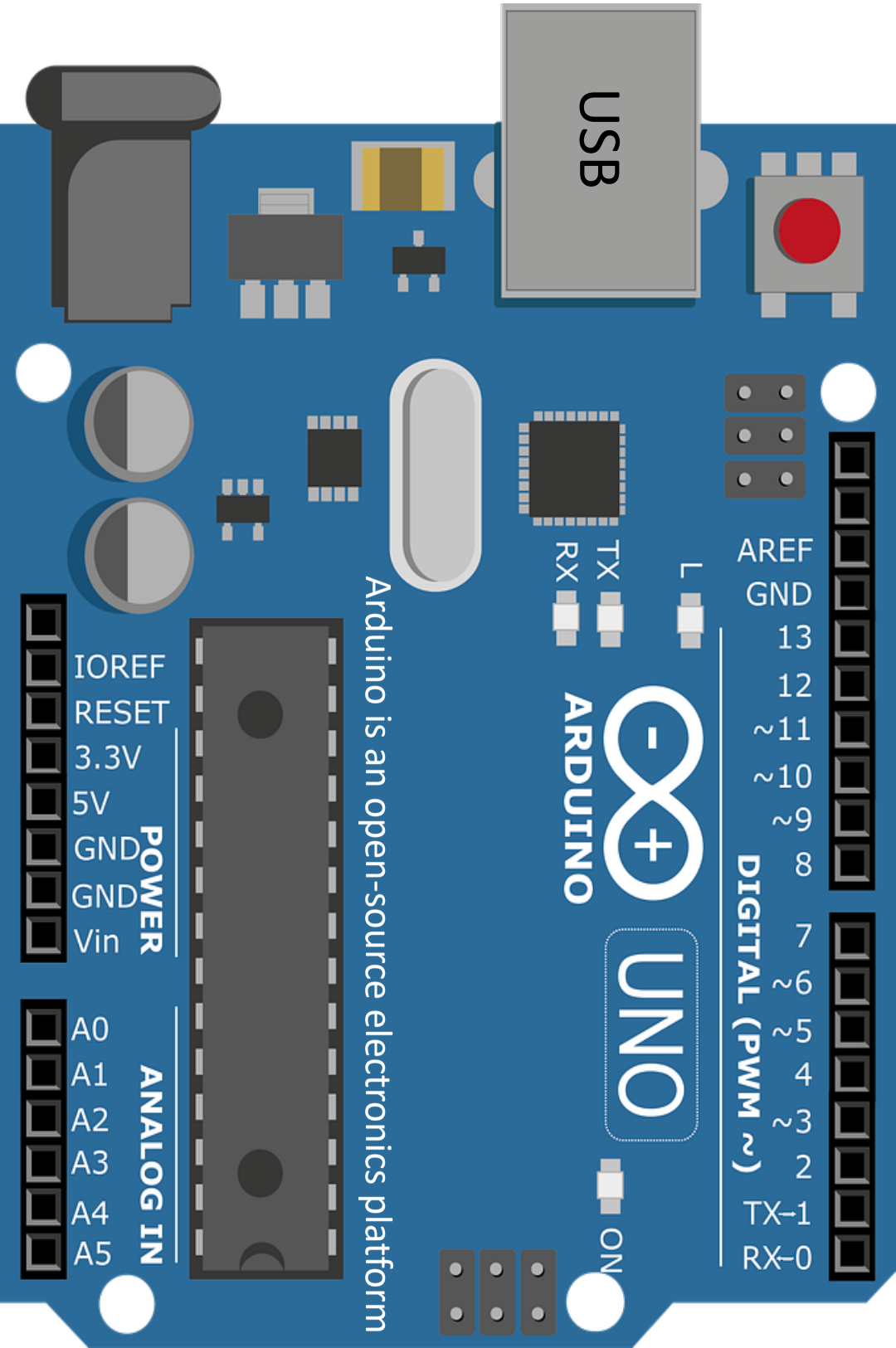
Soon everything will be connected to the Internet – even your Coffee Maker

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.



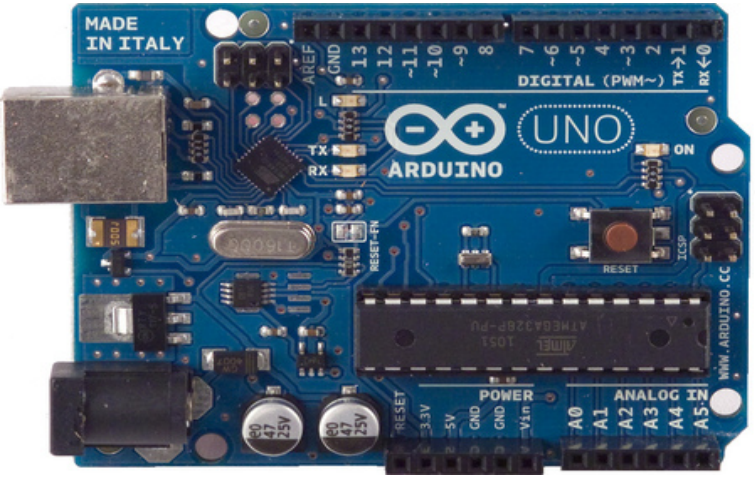


Arduino Microcontroller



Controlling the Air Heater using Arduino

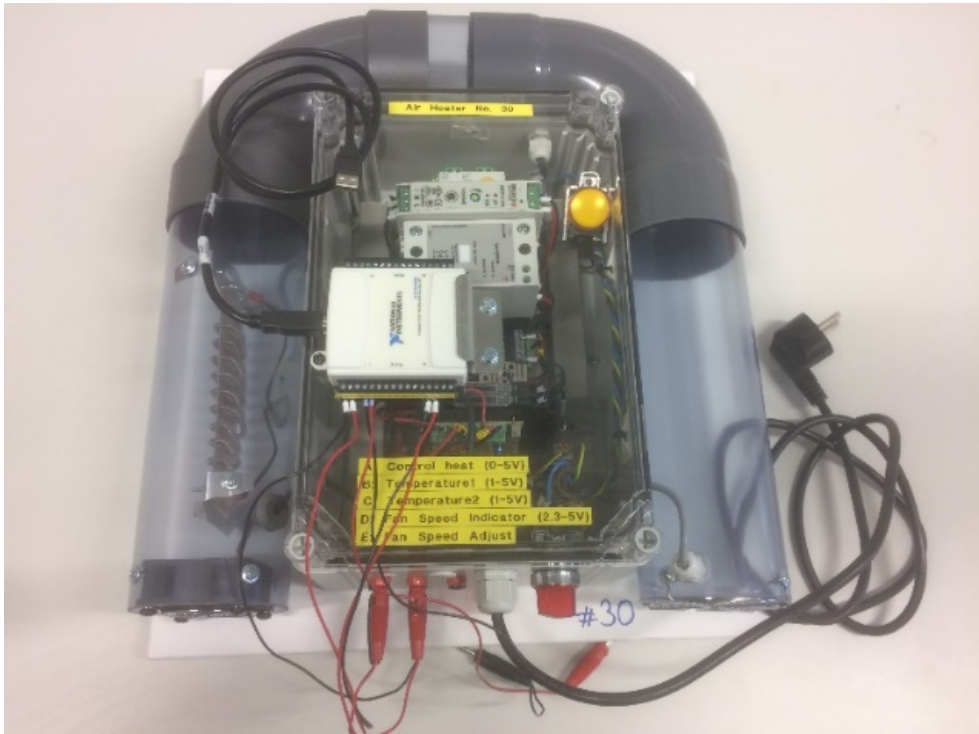
Embedded PID Controller



PV

MV

Air Heater (Process)



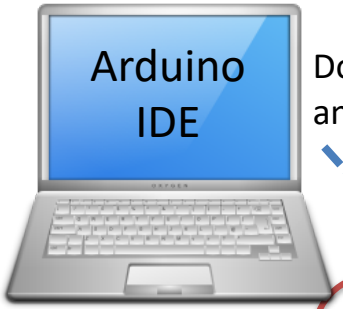
PC as Controller

Industrial PID Controller

Internet of Things (IoT) Control System

Practical Implementation of **IoT**, **Cloud** Computing, and **Embedded** Systems

Compare with commercial PID



Download your Application and then remove USB cable

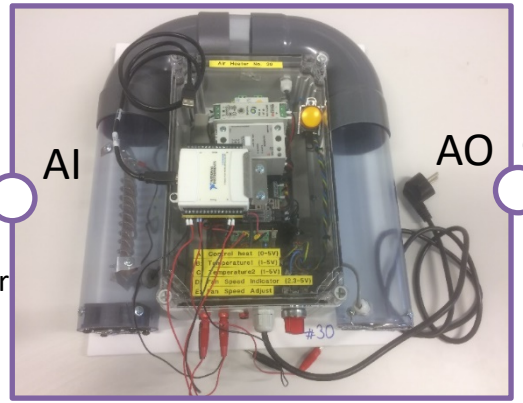
ThingSpeak

Cloud

Cloud-based Publishing of Data

K_p, T_i, T_d r

Air Heater



Banana Connector

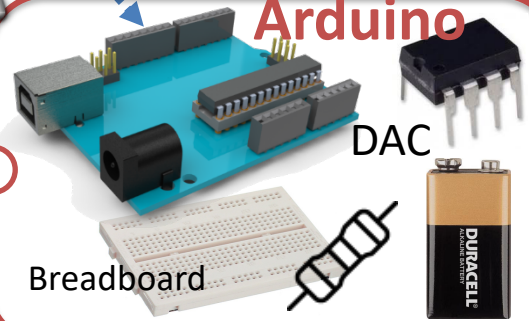
y

Arduino

Analog In

y

Banana Connector



Analog Out

u

Banana Connector

Banana Connector

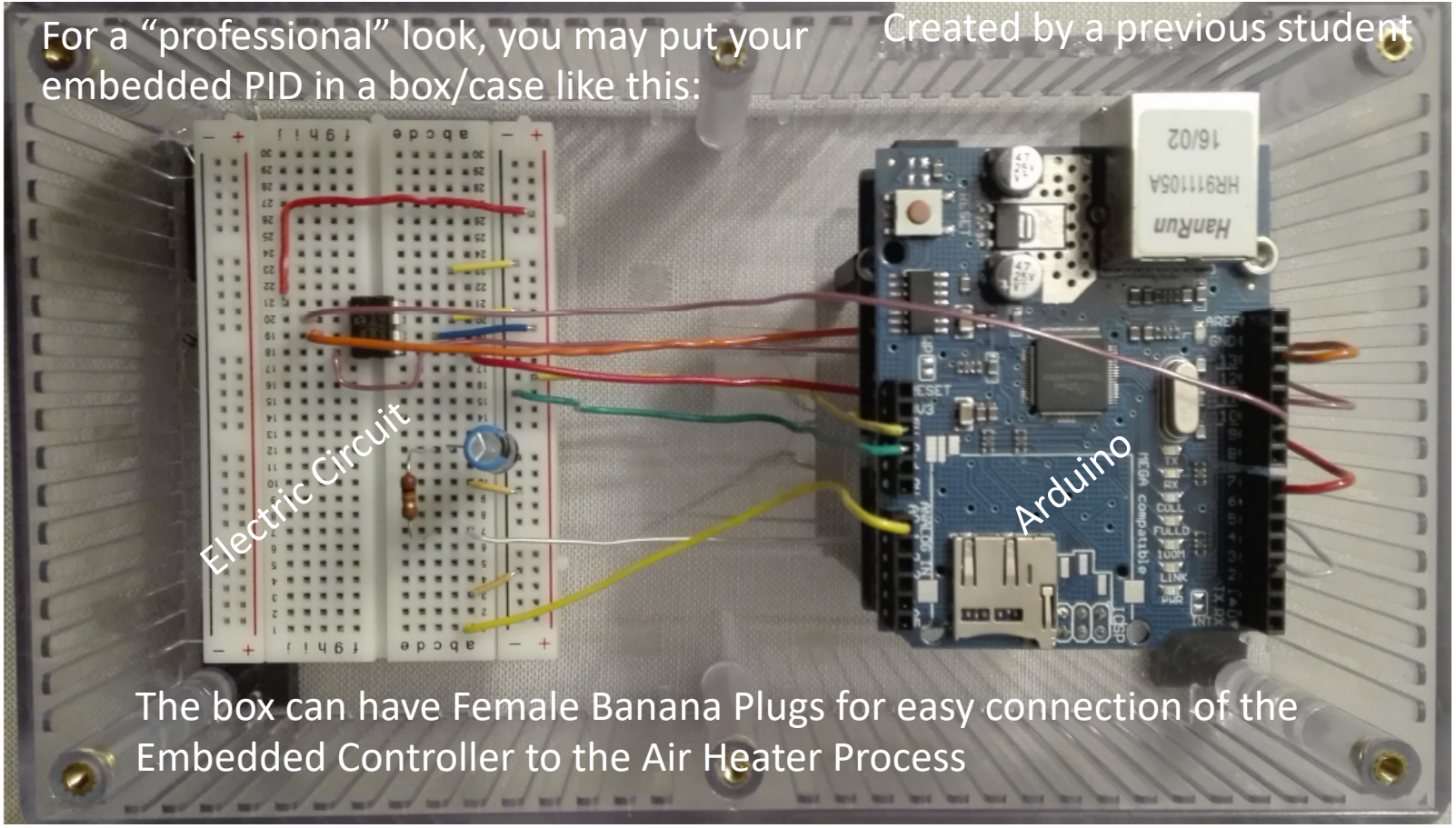
Embedded Arduino PID Controller

Test first using **HIL Simulation and Testing**

Feedback System

ARDUINO

Embedded Arduino PID Example



Lab 3

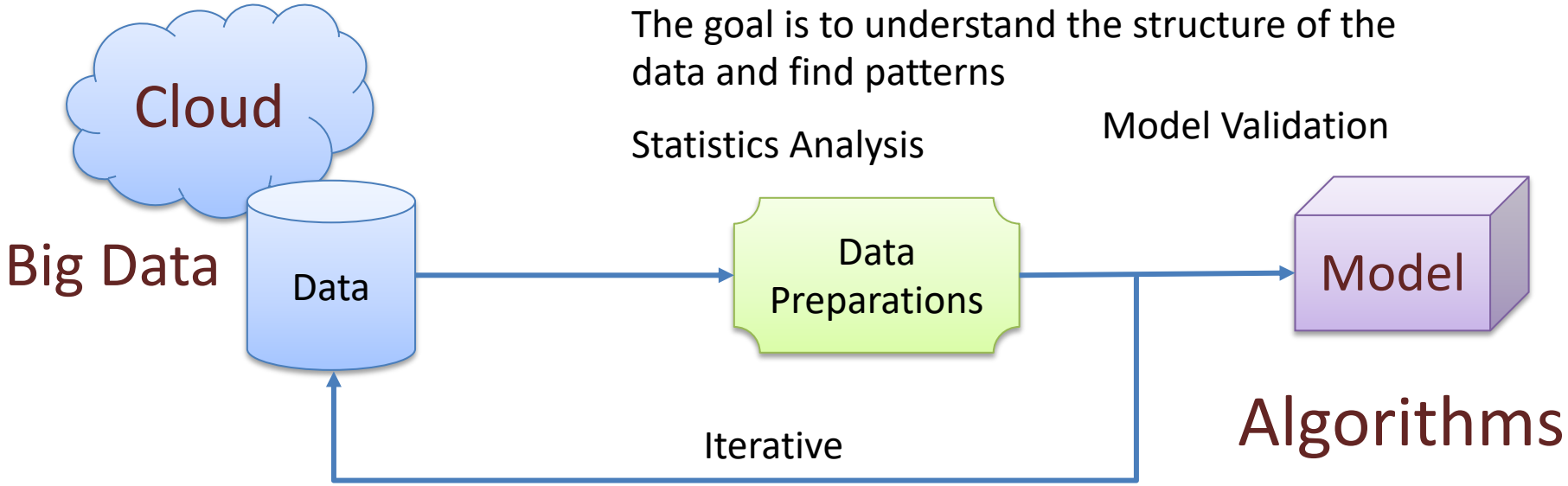
Machine Learning in Automation Systems

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:



Purpose: Control the Level in the Water Tank

Level Tank System

Small-scale Laboratory Process

Machine Learning in Automation Systems

Practical Implementation of System Identification, Kalman Filter, PID, Feedforward and MPC

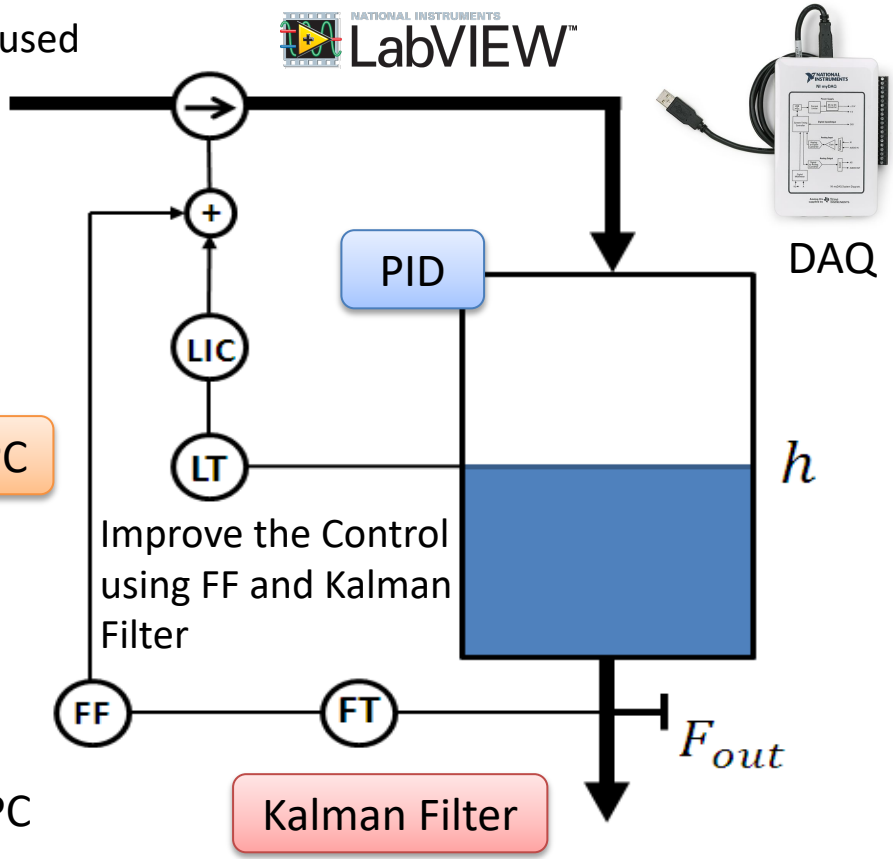
We will apply traditional Machine Learning principles used in Automation Systems such as System identification, Kalman Filter and MPC

System Identification

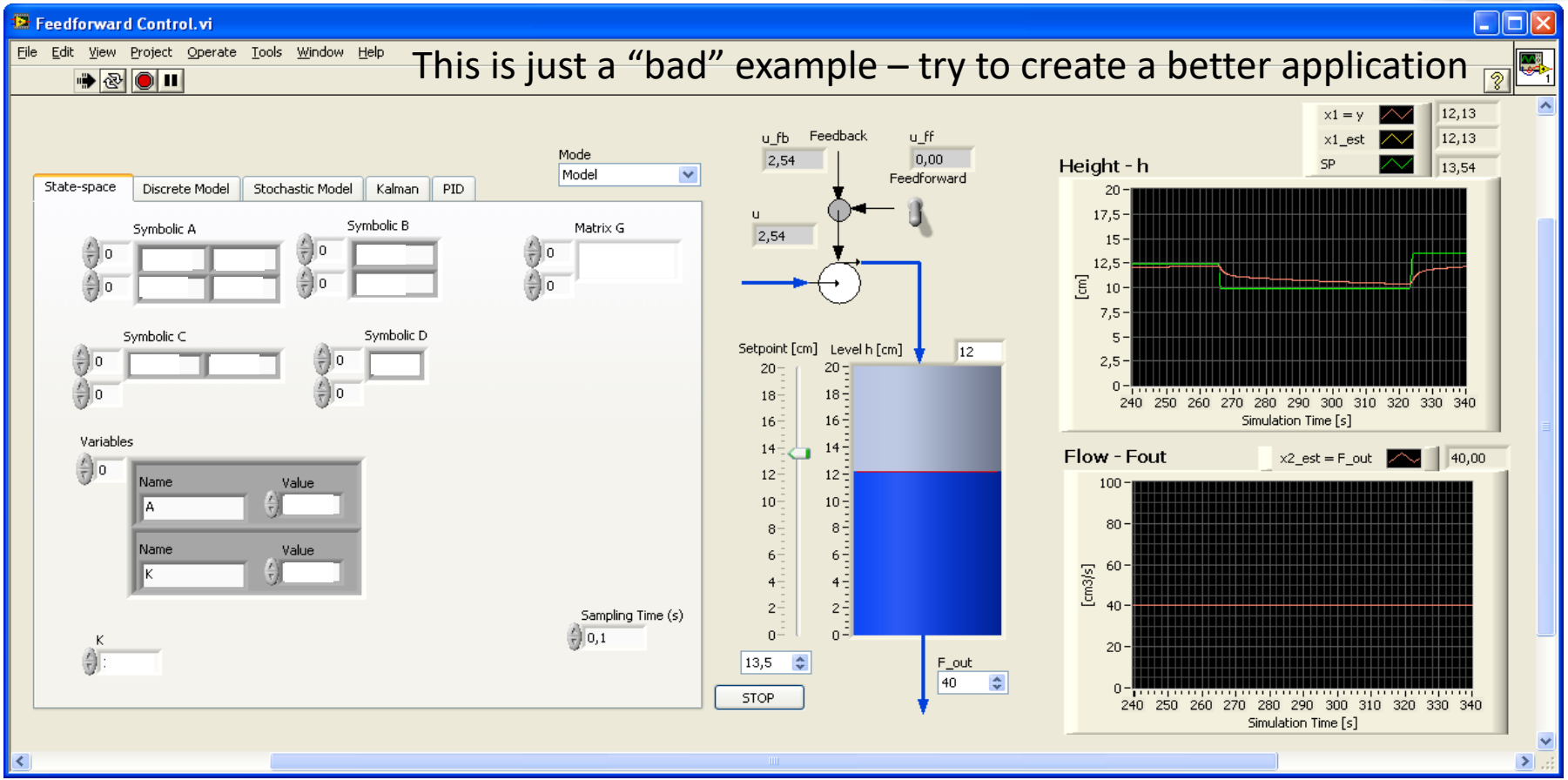
MATLAB

MPC

PID vs. MPC



LabVIEW Example (PID + Kalman + FF)



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

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