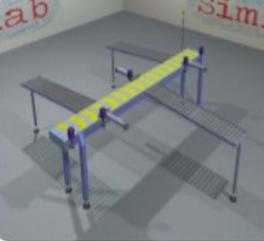
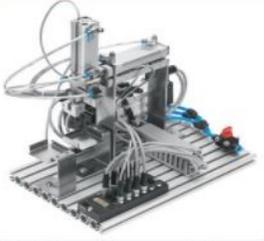


Virtual simulation module for Engineering Education

<p style="text-align: center;">Buttons</p>  <p>Buttons and signal lamps are using simple digital inputs and outputs . These are most common signal types of PLC controllers.</p> <ul style="list-style-type: none">  Learning  Video  Exercises  Evaluation 	<p style="text-align: center;">Electric Motor</p>  <p>Electric motor is an important component of industrial automation system. Electric motor speed is controlled with variable signals.</p> <ul style="list-style-type: none">  Learning  Video  Exercises  Evaluation
<p style="text-align: center;">Conveyor</p>  <p>Conveyor is industrial application for moving packages into correct places.</p> <ul style="list-style-type: none">  Learning  Video  Exercises  Evaluation 	<p style="text-align: center;">Sorting System</p>  <p>Sorting system is industrial application for sorting different types of items by detecting their properties and moving items to correct slots.</p> <ul style="list-style-type: none">  Learning  Video  Exercises  Evaluation
<p style="text-align: center;">Sorting System</p>  <p>Sorting system is industrial application for sorting different types of items by detecting their properties and moving items to correct slots.</p> <ul style="list-style-type: none">  Learning  Video  Exercises  Simulation  Evaluation 	<p style="text-align: center;">Manipulator</p>  <p>Manipulator systems are used when materials have to be moved in different axes and lifted or different places.</p> <ul style="list-style-type: none">  Learning  Video  Exercises  DistanceLab  Evaluation

Editor: Raivo Sell
Corrector: Kaupo Raid

This book has been completed on the frame of Erasmus+ project: 2015-1-EE01-KA202-013471
Project website: simlab.roboticlab.eu

Published by Robolabor.ee kirjastus (ITT Group OÜ) 2017

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This project has been funded with support from the European Commission. This publication reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

ISBN 978-9949-88-047-8 (pdf)

Preface

This book is a output (O3) of Erasmus+ project called: “Online labs and virtual simulators for engineering education”, in short: SimLab. The project idea is to offer online lab platform combined with curriculum module and open learning content for educational institutions. The online lab platform is integrating existing and new remote and virtual labs into one portal by creating unified interface and sharing functionality. Within this project a cross-platform solution for different types of online labs has been developed. Main industrial application and processes like conveyor systems, sorting systems and manipulators have been virtualized and connected with curriculum modules where special attention is payed for IGIP engineering module and CDIO framework.

One of the priority of SimLab project is the enhancement of digital integration in learning. The project is designed to support teachers, trainers and other educational staff in acquiring or improving the use of ICT for learning. The outcomes of the project are enabling access to different kind of remote lab resources offered by the online lab provider network.

The project have three integrated outputs:

O1 Unified distance learning web interface

Unified distance learning web interface is a web based software which enables to access online labs running the virtualized simulation models (O2). Modernized user interface is designed for simulation based labs and unified interface for both: virtual and real online labs.

O2 Virtualized simulation models

Virtualized simulation models are simulated experiments for common industrial applications needed for practical experimentation. PLC based control system exercises can be carried out by using simulation models instead of real machines.

O3 Curriculum module

Curriculum module is a modular unit unified for general mechatronic, ICT or other engineering curricula. The module is developed in an open architecture that enables it easily to integrate into existing study process in different levels of education. Even the first target group of this module is VET institutions and continuous education learners, the module is suitable also for universities and school education learners. This output provides educational frame for previous software and hardware solutions.

Project coordinator:

ITT Group OÜ
Tallinn, Estonia



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Introduction

Visions of manufacturing automation 25 years from now is very well defined by Control Engineering magazine. *“Computerized product design and development will be integrated with simulation software as never before. Simulation techniques will have matured from years of experience with numerous reference models and feedback from real-life applications.”*¹

The vision describes realistic automation future. The products like YuMi Robot by ABB and HoloLens by Microsoft are already here. The concepts like Digital Twin by General Electric and other simulation-based concepts are spreading fast from the state-of-the-art to standard technology. The EU standards and regulations have already set ambitious goals for energy efficiency of electric motor drives and other machines and devices.

With this study module you will take your first steps in PLC Programming and Simulation Tools. Are you ready for the future?

¹ Visions of manufacturing automation 25 years from now, Frank Bartos, PE

Curriculum module

Title: **Introduction to industrial control systems**

Topic diversity: This curriculum is mainly meant to be used in higher vocational schools for basic learning of industrial automation systems. Topic 2, motor simulation, is done for master level education at university. The 4 topics for vocational schools could be used within already existing courses or as a standalone course. The number of credits depends on how much of the material that is used, it could be in between 2-4 ECVET credits. For the vocational part the prerequisites is basic electronics for secondary school.

Aim

With this study module you will learn the basics of Programmable Logic Controller (PLC) programming as well as the fundamentals of simulation of systems.

Learning outcomes

After completing the module student shall:

- understand the concept of PLC as tool in automation
- be able to use Inputs and Outputs (digital, simulated exercise 1)
- know the basics of PLC programming (simulated exercises 1-3)
- understand timing and sequences (simulated exercises 2-3)
- be able to perform testing and fault searching: finalizing the PLC program

Study methods & concept

CDIO: Conceiving — Designing — Implementing — Operating

The CDIO™ INITIATIVE is an innovative educational framework for producing the next generation of engineers.

The framework provides students with an education stressing engineering fundamentals set in the context of Conceiving — Designing — Implementing — Operating (CDIO) real-world systems and products. Throughout the world, CDIO Initiative collaborators have adopted CDIO as the framework of their curricular planning and outcome-based assessment.

The CDIO Initiative was developed with input from academics, industry, engineers, and students and was specifically designed as a template that can be adapted and adopted by any university engineering school. Because CDIO is an open architecture model, it's available to all university engineering programs to adapt to their specific needs and it is being adopted by a growing number of engineering educational institutions around the world. CDIO is currently in use in

university aerospace, applied physics, electrical engineering, and mechanical engineering departments.

In practical level CDIO is based on two main documents: CDIO Syllabus and 12 CDIO Standards. The first one offers a topical list of qualifications which modern and next generation engineers should possess. The second is related to management, leadership and administration of the university or faculty (overall development of learning and teaching skills).

Flipped classroom concept

The **flipped classroom** approach has been used for years to motivate students to take “ownership” of their learning. In the flipped classroom model *first-exposure learning* prior to class and focus on the *processing* part of learning are pointed out (synthesizing, analyzing, problem-solving, etc.) in class. To ensure that students do the preparation necessary for productive class time, Walvoord and Anderson² propose an assignment-based model in which students produce work (writing, problems, etc.) prior to class. The students receive productive feedback through the processing activities that occur during class, reducing the need for the instructor to provide extensive written feedback on the students’ work.

The simplest way to start with this model is to give assignments to the students (video, task, exercise, brainstorming, description of operation of a machine etc.) as a trigger of the learning process prior the lectures. In this way the students are all ready orientated to the topic and they can run the learning situation by setting questions and problems instead of the lecturer. The model can be used in this study module in courses which produce the basic knowledge and skills in programming.

The International Society for Engineering Education - IGIP

The International Society for Engineering Education IGIP was founded in 1972 at the University of Klagenfurt (Austria). International Society of Engineering Education created an international register of engineering educators, which since then guarantees minimum standards in technical expertise and a well -balanced competence profile for engineering educators. The register lists qualified educators who had gone through a curriculum which has been approved by IGIP. Those registered are International Engineering Educator and can use the title ING-PAED IGIP. IGIP accredits training centers for "International Engineering Educators", whose teaching matter conforms to IGIP's curriculum for engineering pedagogy.

The aims of the International Society for Engineering Pedagogy (IGIP) are

- improving teaching methods in technical subjects
- developing practice-oriented curricula that correspond to the needs of students and employers

² <https://cft.vanderbilt.edu/guides-sub-pages/flipping-the-classroom/>

- encouraging the use of media in technical teaching
- integrating languages and the humanities in engineering education
- fostering management training for engineers
- promoting environmental awareness
- supporting the development of engineering education in developing countries

New competencies of educators are needed as

- evaluation management
- development competencies
- communication skills
- teamwork
- ethics and intercultural competencies

IGIP wants to intensify the international cooperation with other societies dedicated to engineering education, such as IEEE Education Society, ASEE, the American Society of Engineering Education, SEFI, the European Society for Engineering Education, or IFEEES, the International Federation of Engineering Societies.

By passing the prototype curriculum as proposed by IGIP in any accredited institution worldwide, IGIP states that a given engineering educator with an ING.PAED.IGIP title has all the competencies needed to teach at the state of the art with the best available teaching technologies.

IGIP curriculum is a modular system which consists of:

- core modules (8 Credit Points),
- theory modules (4 CP),
- practice modules (8 CP).

The core modules include

- theoretical and practical engineering pedagogy,
- laboratory methodology.

The theory modules include

- psychology,
- sociology,
- ethics,
- intercultural competencies.

The practice modules consists of

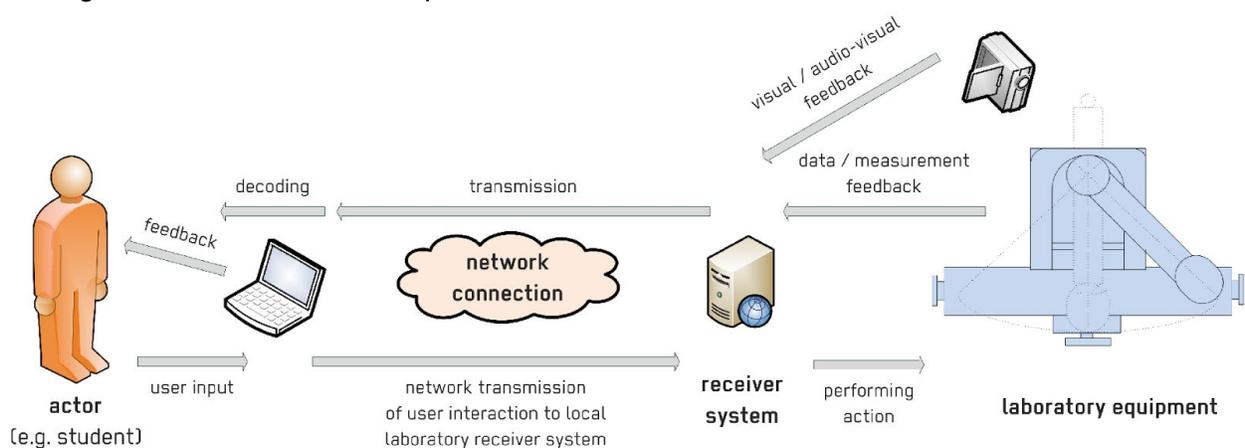
- oral communication skills,
- scientific writing,
- working with projects,
- media,
- e-learning, and computer aided technologies,
- module free for additional topics.

Virtual and remote labs

A remote lab (online lab) allows the user carry out experiments over the Internet that are usually done in the lab. What make it different from the usual lab are the equipment and communication channels that are needed in order to carry out an experiment remotely.

Remote Lab

In the case of a remote lab, the user interacts with the device over the Internet. This means that the user sits behind his/her computer or mobile device and the lab devices are in school or somewhere else, not in the immediate vicinity of the user. The user does not interact directly with the device, but through specific software. The software may be a standalone program or a web application that operates via a usual browser. The user's instructions are sent to the device over the Internet. Usually, the user does not interact directly with the device, but this is done through intermediating servers that administrate devices, deal with security issues, etc. As it is difficult to execute some of the activities through software that would be easy for a human being, e.g. pushing a button, some functionality may be limited in the case of a remote lab. Usually, control software and the device exchange electrical signals and most of the functionality can quite simply be converted into electrical signals as a rule. One distinct exception is the physical movements of the user, which are too expensive or too complicated to execute in the case of a remote lab. Feedback about the behaviour of the machine is obtained through a real-time camera, of which there may be either one or many, depending on the device specifics. Audio feedback is also possible and it is usually integrated with the real-time camera. The figure below shows the setup of a remote lab.

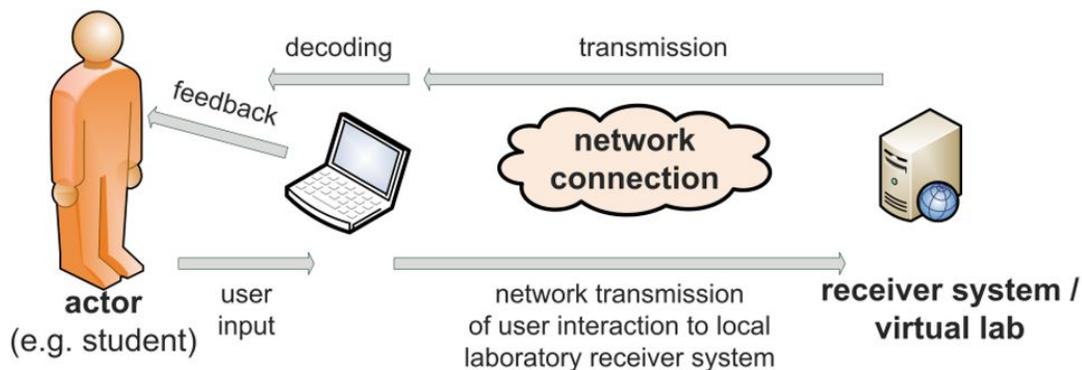


Lab experiments play an important role in technical study fields, and they are usually defined on a course's subject map. Students have to perform the experiments at certain times, when lab equipment is free or booked for this specific study group or student. These times generally coincide with study times and the official working hours of the school. Insufficient or lacking lab equipment may often be a problem, as well as access to the equipment because of the number

of users being larger than free time resources. It is in a situation like this that using remote labs may be a good idea, as they are much more flexible in usage time – a student may perform experiments over the weekend or at night if he/she so desires. Another significant advantage of using a remote lab is access. Experiments can be carried out regardless of the geographical location and there is no need to arrange special access to lab rooms. Sharing the resources of the owners of the remote lab and schools is also important. This makes it possible to use practical lab experiments in schools that do not have the necessary lab equipment. All that is needed is an agreement with the owner of a remote lab, e.g. another school.

Virtual Labs

Virtual labs are a special type of remote labs that work in a similar fashion to the remote labs described above, but they do not have actual hardware or lab equipment. Lab equipment and system behaviour are simulated using special software. System feedback is not obtained through measuring the output of an actual system, but by simulating software computations. The output of the simulator may be only textual, but for the sake of attractiveness and clarity, virtual labs with graphic output are preferred. For example, when the user inputs a program, graphical objects start to change their states – like the colour of a circle changing, which stands for the lighting up and extinguishing of a LED. The setup of a virtual lab is shown on the figure below.



One of the advantages of a virtual lab is that they are easy to maintain (no need for servicing hardware) and easy to replicate. The number of virtual lab devices usually depends on the capacity of the server and the number of licenses only. A drawback of virtual labs compared to remote labs is their simulation-based output. A simulated system never acts exactly like an actual system. Therefore, it is important that students should get an experience of the studied problem through an actual experiment, but a virtual lab will be very good at first, as it can easily be provided for a larger number of students and it is almost impossible to break because of inexperienced handling.

DistanceLab usage guideline

The DistanceLab (<http://distance.roboticlab.eu>) web portal and framework enables to access virtual simulation engines but also remote labs and facilities linked to the system. This platform enables to access different facilities despite of location and time. Devices and systems can be put easily online and then access to the either virtualized or real system over the web to run staff training programs, remote control procedures or remote monitoring and energy efficiency and productivity evaluation.

Video here is explaining one example how the DistanceLab can be used for remote micro controller programming: <https://youtu.be/7fQAT4zlc20>

In this document you find some literature and links for performing the labs. The exercises 1-4 are found in this page <http://distance.roboticlab.eu/menu/index/64>. For corresponding Festo labs, 3 and 5, this link is valid <http://distance.roboticlab.eu/menu/index/63>.

Simulations

Simulation engine for Siemens PLC simulations

Simulations are commonly used in industry and academia for understanding complex behaviours of different systems. A simulation engine is a program running on webserver or local computer. This program is interpreting (via a mathematical model) a real system and user will get visual feedback how the system behaved. Simulation engine (the core program) for Siemens PLC is a simulation software solution based on Siemens STEP 7 Manager Software and Siemens simulated PLC (PLCSIM). Special middleware software is developed for interpreting Siemens STEP 7 manager output and generating input for graphical simulation model.

The simulation model is application specific and can be rather easily developed for any similar system when whole framework is provided.

A student licenses is needed to run the software which can be acquired from the Siemens Partner/Website or these tools can be provided by your institute. The program is not available on the DistanceLab portal.

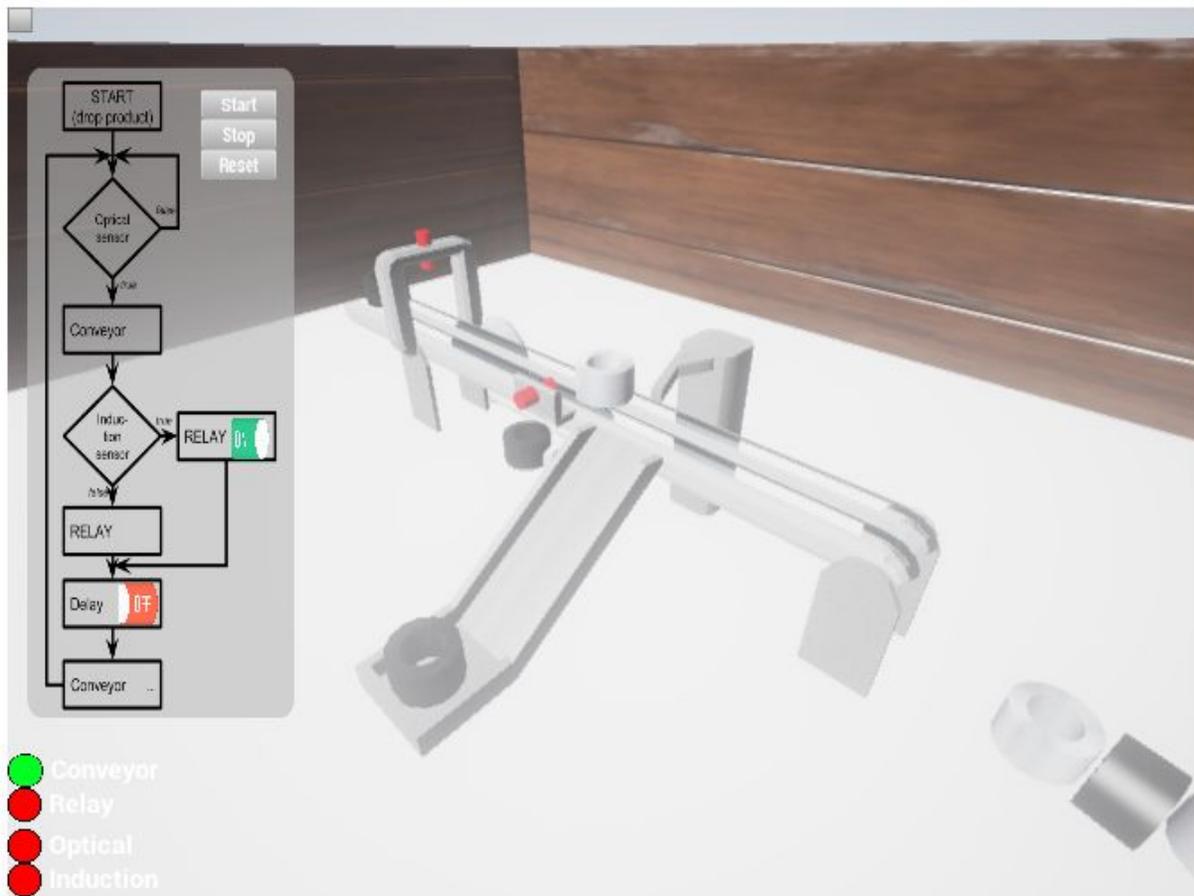
For setting up the system follow instructions on website.

Simulation engine for Festo

The second approach we have implemented is focusing on common understanding of industrial process and simulation of basic algorithm. It is vendor independent solution and enables to practice main control algorithm development for industrial systems. As an example Festo Mecalab hardware is taken for remote lab and virtualized digital twin. However the programming and control of Festo actuators and reading sensors is replaced by microcontroller based system enabling to control the devices with program written in C language. This system is fully browser based and no need for special hardware or software. No licenses, just common web browser and reasonable internet speed is required.

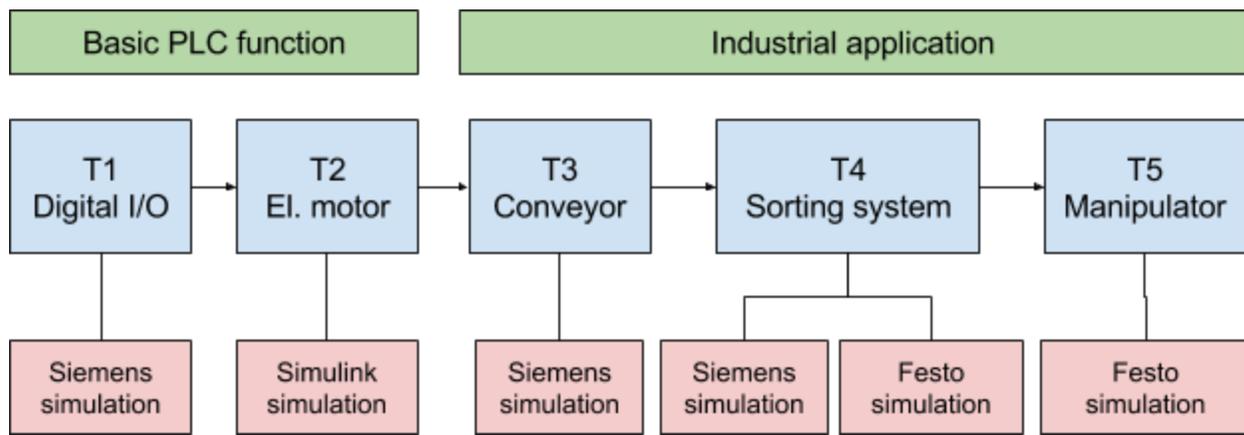
In a picture below one working example is shown.

To test the system one can use our VirtualLab environment for more information: <http://distance.roboticlab.eu/menu/index/63>



Topics featuring simulation models for curriculum

This curriculum module consists of 5 virtual topics: 1) Digital Inputs and Outputs (Push Buttons and Signal Lamps), 2) Electric motor modeling/simulation, 3) Conveyor, 4) Sorting System and 5) Manipulator. Exercises are covering basics functions as well as basic systems of industrial applications. However simulation models for exercises are designed for different complexity level, meaning that some practical simulations are suitable for vocational education and one (T2) for master level.



All topics are described in following structure:

- Name of the topic
- Learning outcome descriptions
- Practical task
- Simulation tool web link
- Suggested background reading list
- Self assessment questions which are implemented on the website and can be tested online (see appropriate simulation model site)

Topic 4 has two different practical tasks based on different hardware solutions. Teacher or student should select the one which is appropriate for the level and hardware preferences of particular case or target group.

It is also important to realize the in addition to virtual simulation, the Topic 4 Festo sorting system has also real remote lab solution enabling to control real hardware if there is permission and access from the lab owner.

Topic 1 ON/OFF signals - Buttons and lamps

Buttons and signal lamps are using simple digital inputs and outputs i.e. ON/OFF signals. Digital inputs and outputs signals are most basic and also most common signal types on PLC controllers. With input signals controller can acquire information from sensors or human operators. For example contact sensors or contactless proximity sensors inform controller that some object is touched or is apparent in range. Based on this data PLC can generate output signal to stop the motor, light up the signal lamp etc. Simple buttons act as digital inputs and enables to provide human interaction to machine.



Learning outcomes

After completing the topic student shall be able to...

- handle digital inputs and outputs,
- use and change parameters in program blocks,
- set and reset bits,
- use timers and counters in program,
- connect digital inputs and outputs in a proper way.

Task

Write a PLC program that controls the digital outputs by change of state of digital input.

- a. the signal lamp (Q0.7) blinks every time you press the push-button (I0.0)
- b. add 3 second delay in your program
- c. add a counter in your program, which calculates how many times you have pressed the push-button
- d. display the value of the counter as a binary code with signal lamps

Simulation tools

[VL Siemens PLC - Buttons](http://distance.roboticlab.eu/menu/index/64) [http://distance.roboticlab.eu/menu/index/64]

Suggested readings

1. General topic: Programmable Logic Controller (PLC), <https://www.myodesie.com/wiki/index/returnEntry/id/2962>
2. Video: PLC What it is and how it works, <https://youtu.be/rh5DfK2JWmA>

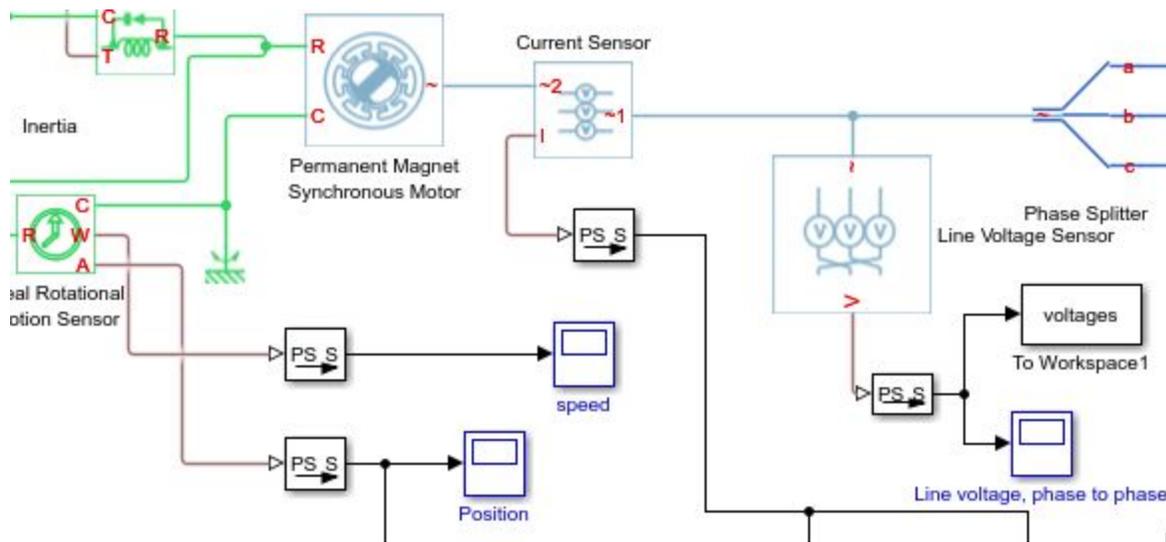
Self assessment questions

1. What programming method or language is commonly used for making program for PLC (e.g. Siemens S7)?
 - a. C programming language
 - b. HTML descriptive language
 - c. Ladder diagram
 - d. PLC-s have no programming option
2. What type of signal is defined for PLC in case of interfacing standard push-button
 - a. Digital input
 - b. Digital output
 - c. Analog input
 - d. Analog output
3. What are the possible values for one bit?
 - a. 0 and 1
 - b. -1, 0 and 1
 - c. 0 - 255
 - d. Any positive natural number
4. What is the purpose of using PLC Timer?
 - a. Count user inputs
 - b. Generate delays
 - c. Show current date and time
 - d. Control and coordinate PLC internal frequency

Topic 2 Simulation of electric motor (PMSY) and control.

Electric motor is an important component of every industrial automation system. Electric motor speed is controller with variable signals like analog, PWM or frequency signal.

The permanent magnet synchronous motor (PM synchronous or PMSY motor) is perhaps the most dominant motor for automation equipment in the engineering industry, for example, industrial robots and numerically controlled machines. Part of the simulation model is illustrated below.



The level of these exercises are on master level.

Learning outcomes:

After this course student shall be able to:

- understand the function of a PMSY motor,
- build a model of a PMSY motor,
- perform simulations for both open loop and closed loop control of PMSY motor.

Task

Modelling, simulation and analysis of PMSM-machine with inertial load

When the rotor of the machine is rotating at constant speed and torque, the currents and voltages will be three phase AC. When the machine is at stand still, the voltages and currents will be DC. The data for the motor to be modelled in the following exercises is given below. Pre-made models in Simulink and change variables are available for this task.

Motor to be modelled:

6SM107S-3000 (Note RMS values)

Torque constant: $K_T = 1,6 \text{ Nm/A}$

Voltage constant: $K_E = 97 \text{ mVmin}$

Rated Torque: 23 Nm

Winding resistance Phase-Phase: 0,37 ohm

Winding inductance Phase-Phase: 3,6 mH

Rotor moment of inertia: 104 kgcm²

Motor pole no.: 6

Thermal time constant: 40 min

Weight standard: 32,5 kg

Exercise 1 No-load and short circuit tests

This exercise uses the Simscape model: *noload_shortcircuit_tests.slx*. The purpose of the exercise is to adjust the parameters of the simulation model to the machine to be modelled. These tests are also performed on real machines to determine or verify the parameters of a machine e.g. the voltage constant.

- Calculate the no load line voltage and the short circuit current at 1000 rpm.
- At which speed is it acceptable to short circuit the machine and why?
- Choose the parameters of the machine model to match the machine data above and verify the choice with no load (open circuit) and short circuit test.

Guidelines: Adjust the parameter Ψ until the no load voltage becomes correct according to calculations in

Only two experiments is needed, why? When the no load voltage is correct then also flux linkage Ψ is correct (for a certain pole number). After that a short circuit test at 1000 rpm can be performed to verify that the short circuit current becomes the same as in the calculations in a). This indicates that the impedance (or indirectly R, L) of the machine is correct. In a real machine the short circuit current would be too large and the speed should be reduced to value calculated in b), but this is a simulation.

- Check the relation between the electrical and mechanical frequency.
- Write a m- file in order to insert the model parameters automatically, to be used in upcoming exercises.

Exercise 2 DC-current excitation of the machine

Use the Simscape model: *DC_current_phasor.slx*. Use the m-file you made to get the parameters for the machine model.

Inject the following current phasors (stator coordinates)

- 1) 10A
- 2) j10A

- a) Compare the results and give a qualitative explanation.
- b) Measure the phase currents a, b, c and explain their relation to the current phasor in stator coordinates.

Exercise 3 Excitation with synchronous rotating current phasor

(stator coordinates) = DC current phasor in DQ rotating coordinate system

This exercise uses the Simscape model: *current_phasor_commutation.slx*. Use the m-file you made to get the parameters for the machine model. In reality the machine is feed by current controlled voltage sources rather than current sources as in this example. Deeper study of this topic is in exercises about control.

Inject the following current phasor in DQ-coordinates (rotating coordinates).

- 1) 10A (pure D current)
- 2) j10A (pure Q current)

Compare the results from 1) and 2) and give an explanation of the behavior of all the measured mechanical and electrical quantities.

Cascade control for the simulated PMSM-motor

The PMSM machine from the actuator exercises is now to be used for cascade speed control. First the inner current (torque) control loop is tuned, after which an outer speed control loop is designed.

Exercise 4 Excitation with three phase voltages and current controllers

This exercise uses the Simscape model: *current_control.slx*. Use the m-file you made to get the parameters for the machine model.

In this exercise the current generators are replaced with voltage generators controlled by current PI-controllers and feedback of measured currents. The current feedback signal is filtered.

Adjust the PI controller, is it possible to eliminate the static error? It is not required to optimize the controller by e.g. pole placement, just to tune it by trial and error.

Exercise 5 Cascade control, design of speed loop

Use the Simscape model of the current controlled machine from the previous exercise and design an outer speed control loop.

Simulation tools

Simulink/Matlab ver 2015a

The models should only be downloaded to your computer and run them on Simulink software.

[Noload_shortcircuit_tests_ver15a.slx](#)

[<https://drive.google.com/open?id=0B2gbVGz1HbYtTWF2Q25nZDIsoWM>]

[DC_current_phasor_ver15a.slx](#)

[<https://drive.google.com/open?id=0B2gbVGz1HbYtOU9ISXB5ZHIhejQ>]

[Current_phasor_commutation_ver15a.slx](#)

[<https://drive.google.com/open?id=0B2gbVGz1HbYtYIRVUXh0VkFhTEU>]

[Current_control_ver15a.slx](#)

[<https://drive.google.com/open?id=0B2gbVGz1HbYtOEtmaTZiVWRfYVU>]

Suggested readings

[Permanent magnet synchronous machine](#)

[<https://drive.google.com/open?id=0B2gbVGz1HbYtUU1GdjVwS3lubmM>]

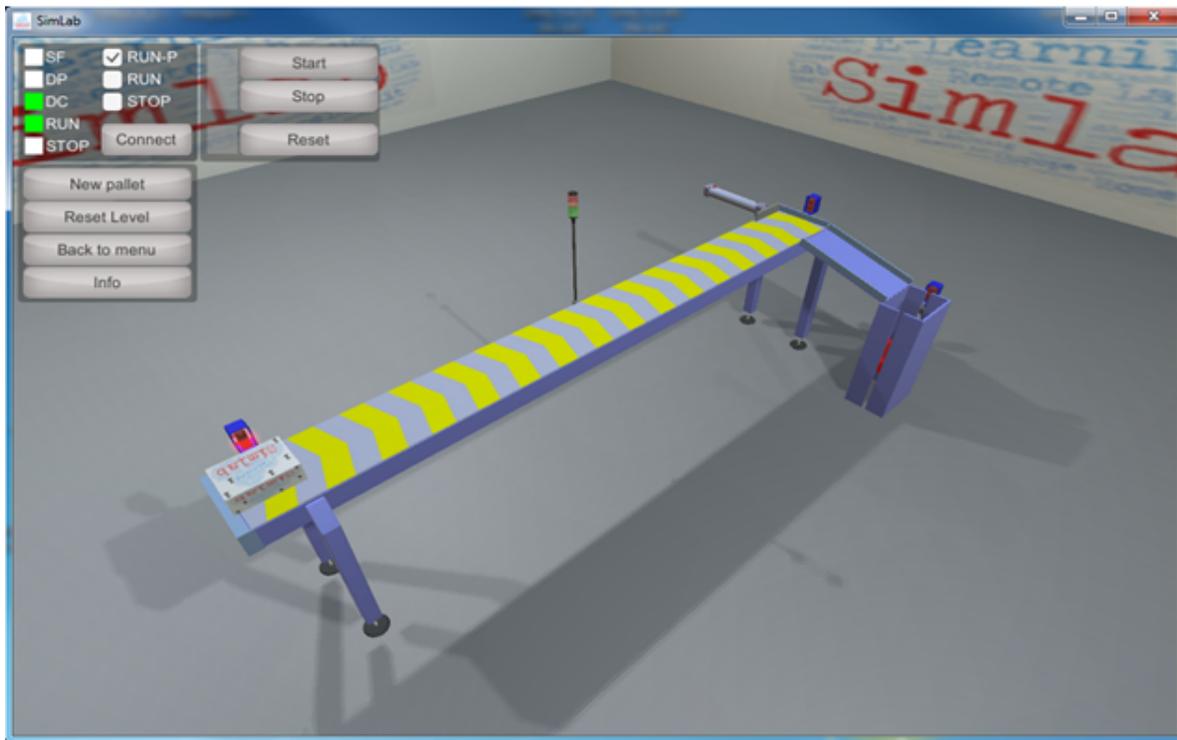
Self assessment questions

1. What main advantage is there for a sinusoidal compared to a trapezoidal commuted motor?
 - a) The current is increasing quickly in one phase and decreased in another
 - b) The currents are square shaped
 - c) The current is increasing smoothly in one phase and decreased in another
 - d) There is no main advantage
2. What will you verify with no load test in an electric motor?
 - a) Internal resistance
 - b) Internal current
 - c) Internal voltage constant
 - d) Internal impedance
3. How could you get the impedance of the motor?
 - a) By making a short circuit test
 - b) By measuring the impedance of the motor
 - c) By making a no load test
 - d) By measuring the speed of the motor
4. Why is it not good to make a short circuit test in reality?
 - a) Current through stator windings will overheat the windings and damage them
 - b) The current becomes too high
 - c) It's easier to make short circuit test in virtual environment

d) The voltage becomes too high

Topic 3 Conveyor

Conveyor is industrial application for moving packages from one place to another. Conveyors are very common in production industry. The conveyor is often used in combination with a stacker. In the stacker a pile of products is stacked for making transport of them easier. In production you have to count the number of produced products, that will be done by the counters connected to sensors on the conveyor system.



Learning outcomes:

After this course student shall be able to:

- read sensor data with PLC Program (Inputs),
- control the outputs i.e. actuators like motors, cylinders etc,
- understand the principles of well designed PLC program,
- understand test procedures of a PLC program.

Task

Write a PLC Program for the conveyor system. You will find the description of operation of the machine below. Test your program with a simulation tools.

Conveyor system should make a stack of 7 boxes at the end of the conveyor and move the stack to the warehouse, which is below the stacker (downstairs).

The conveyor starts by pressing the Start-Button (I0.0) after 3 seconds delay. The Start-Button also activates automatic mode. Machine will be stopped by pressing the Stop-Button (I0.1). The conveyor M1 moves the box to the end of the conveyor, when sensor S2 (I1.2) detects it. The Pneumatic Cylinder Y1 (Q1.1) pushes the box to the ramp and the box drops to the stacker. The cylinder has limit switches in both ends S4 (I1.3) and S5 (I1.4). The stacker moves up and down with Electric Motor M2 (Up: Q1.2; Down: Q1.3). The stacker has an upper level sensor S6 (I1.5) and lower level sensor S7 (I1.6). The initial position of the stacker is Up.

Sensor S3 (I1.2) detects that the box is on the stacker and the stacker can be moved one step lower to wait another box. The stacker can receive maximum 7 boxes. After 7th box the stacker will remove the boxes in the warehouse (downstairs). During the removal process other actions of the machine should be stopped and the signal lamp should blink red light (H2: Q0.1) with 1 Hz frequency as an alert. Also warning horn/buzzer H3 (Q0.2) should be on and automatic mode off. The removal process will be initiated by Reset-Button (I0.2), which activates cylinder Y2 (Q1.5). Reset-Button also disconnects signal lamp H2 and warning horn/buzzer H3. Automatic mode will be activated by pressing the Start-Button. When automatic mode is ON the green signal lamp H1 (Q0.0) should be ON as well. The next box should be ordered with output Q1.4.

Simulation tools

[VL Siemens PLC - Conveyor \[http://distance.roboticlab.eu/menu/index/64\]](http://distance.roboticlab.eu/menu/index/64)

Self assessment questions

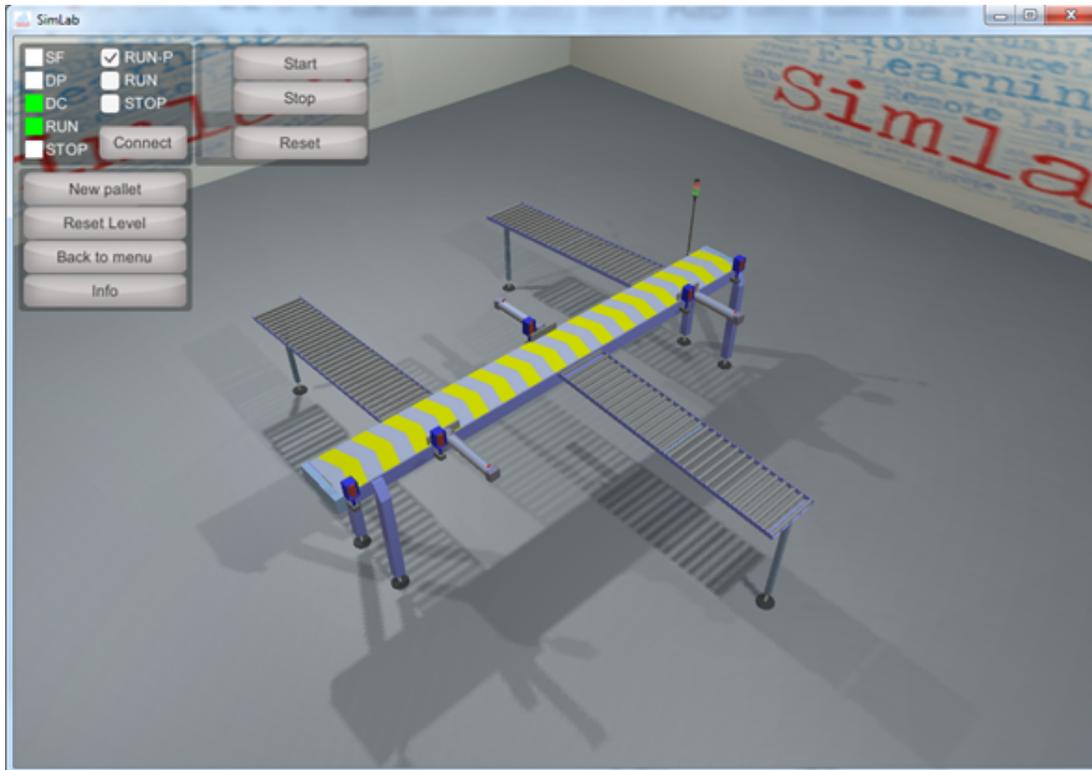
1. What kind of conveyer application you can find in industry?
 - a) Packaging
 - b) Mailing
 - c) Mining
 - d) Musical
2. Find examples of different kind of conveyor types?
 - a) Gravity roller conveyor
 - b) Belt conveyor
 - c) Diagonal conveyor
 - d) Vibrating conveyor
3. How can you control the speed of the conveyor?
 - a) Change speed of drive motor(s)
 - b) Change slope of conveyor
 - c) Increase the amount of rollers in system
 - d) Change belt gearing
4. How you can control the action of pneumatic cylinder?
 - a) By using gas control valves
 - b) By using flow controls

- c) By using quick exhaust valves
- d) By using speed control mufflers

Topic 4 Sorting System

Sorting system is industrial application for sorting different types of items by detecting their properties and moving items to correct slots.

Sorting systems are typical application in industry e.g. sorting postal packages, food industry, waste sorting, etc. There are different sensors and technologies in use to detect object properties and different actuator which move objects to correct slots. There must be correct control program which reads sensors data and drives actuators by taking into account system properties and timing factor.



Learning outcomes

After this course student shall be able to:

- describe functionality of sorting system,
- analyze system components and the functionality,
- create model of the system's working logic,
- develop control program for sorting system,
- validate and test the control solution.

Task (for Siemens VirtualLab)

Main task is to write a PLC program for the Sorting System and test it with a simulation tool.

The Sorting System will sort pallets coming to the conveyor line in 3 categories (roll conveyors). The sorting data is written on a RFID-tag of the boxes (every box have a tag of its own). RFID-readers LP1 (I1.1), LP2 (I1.2) and LP3 (I1.3) read the sorting information from the tag. If the information is correct, the readers set the input of the PLC on.

1. The conveyor M1 (Q1.3) starts by pressing the Start-Button (I0.0) after 3 seconds delay. The Start-Button also activates automatic mode. The system will be stopped with the Stop-Button (I0.1).
2. The conveyor moves the pallets by the RFID-readers and the readers collect the sorting data of the pallets.
3. The Pneumatic Cylinders Y1 (Q1.0), Y2 (Q1.1) and Y3(Q1.2) push the pallets on the roll conveyors if the sorting data in pallets (RFID tags) matches with the reader data.
4. If the pallets reach the sensor S2 (I1.4) at the end of the conveyor line, the red signal lamp H2 (Q0.1) should start to blink once a second as an alert. Also warning horn/buzzer H3 (Q0.2) should be on and automatic mode off.
5. When automatic mode is ON the green signal lamp H1 (Q0.0) should be ON as well. The next pallet should be ordered with output Q1.4.

Simulation tools

[VL Siemens PLC - Conveyor](http://distance.roboticlab.eu/menu/index/64) [http://distance.roboticlab.eu/menu/index/64]

Self assessment questions

1. What kind of sorting systems you can find in industry?
 - a) Pop-up sorters
 - b) Vertical sorters
 - c) Pusher sorters
 - d) Wiping sorters
2. How RFID-tags work?
 - a) By transmitting signal to power on, and reflect energy back to reader
 - b) By giving power to wifi signal
 - c) By using radio signals to transmit data to RFID reader
 - d) RFID tags use GPRS network to transmit data
3. How you can create delays for the pneumatic cylinder actions?
 - a) By using time delay valve
 - b) By using air timers
 - c) By using air bump
 - d) By using speed control mufflers
4. Why you have to make delays for the pneumatic cylinder actions?
 - a) To make pneumatic cylinders faster

- b) To slow down the pneumatic cylinders
 - c) To use pneumatic cylinders action in the right time
 - d) To apply other valves and bumps to the pneumatic cylinder
5. How you can count the number of products sorted by the system?
- a) By heat sensors
 - b) By using camera
 - c) By humidity sensors
 - d) By using proximity/distance sensors

Task (for Festo VirtualLab)

Main task is to write a program for the Sorting System and test it with a simulation and remote lab tools by using actuators and sensors.

1. Write a program that moves building blocks to conveyor.
2. Improve program to check the presence of the blocks
3. Improve program to sort out metal blocks

Single functions to be solved:

- move pneumatic cylinder forward and backward
- check block's presence with optical sensor
- start conveyor to move blocks
- check material inductive sensors (is it metal)
- actuate solenoid to push block down

Simulation tools

[VL Festo HomeLab - Sorting system](http://distance.roboticlab.eu/menu/index/63) [http://distance.roboticlab.eu/menu/index/63]

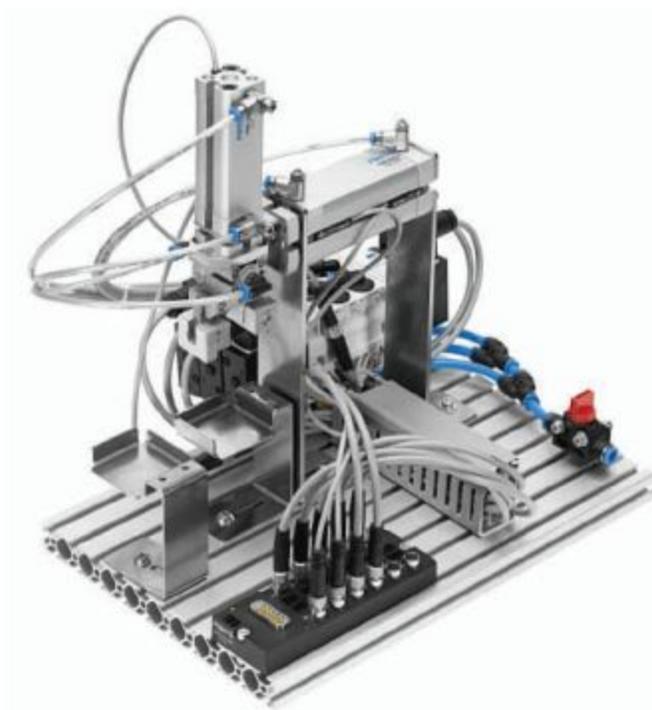
Self assessment questions

1. How to control pneumatic cylinder?
 - a) With a digital output
 - b) With analog output
 - c) With digital input
 - d) With analog input
2. Which is the right ways to control conveyor motor (DC motor)?
 - a) Setting it on and off through the H-bridge (motor driver)
 - b) Running it directly from microcontroller (Atmega2560) digital pin
 - c) Controlling it manually with AC electrical source
 - d) Turning it manually on with DC electrical source
4. Inductive sensor can detect:
 - a) Different plastic materials
 - b) Metal materials
 - c) Liquids in material
 - d) Magnetic materials

Topic 5 Robot manipulator

Manipulator systems are used when pieces have to be moved in different axes and lifted to different places. Robotic manipulators are designed for specific task, i.e. welding or they are universal and can be reprogrammed for different tasks. Pick-and place robot manipulators are common handling devices in industry. The important component of handling device is a gripper which makes contact and manipulates with the target object. Common types of grippers are mechanical and vacuum grippers.

Mechanical gripper have often two or three gripper jaws which “grip” the workpiece like a hand. Since the jaws are not very flexible they must be adapted to the workpiece. Mechanical grippers can be operated by either fluid power (hydraulics or pneumatics) or electricity.



Learning outcomes:

After this course student shall be able to:

- describe functionality of robotic manipulator,
- analyze manipulator capabilities and movement parameters,
- analyze gripper capabilities and limitations of handling target objects,
- develop control program for manipulator,
- validate and test the control program.

Task

In a production line, the robotic manipulator carries workpieces between two stations. Program the manipulator to move target objects from collector end to the upper stack.

Steps:

1. Advance the x-axis when a sensor detects an object but only if the cylinder is in the retracted position.
2. Retract the x-axis when a push-button is actuated, but only if the cylinder is in the extended position.

Simulation tools

[VL Festo HomeLab - Manipulator](http://distance.roboticlab.eu/menu/index/63) [<http://distance.roboticlab.eu/menu/index/63>]

Suggested readings

Festo Meclab getting started workbook 2008 [Found on www.festo-didactic.com website]

Self assessment questions

1. Which are the common methods to identify objects?
 - a) Objects are marked with the identifier
 - b) Objects are made of different material
 - c) Objects are in different colours
 - d) By touching objects from different angle
2. Vacuum grippers are mostly used when
 - a) Objects are very heavy
 - b) Objects are in different shape
 - c) Objects are non-magnetic
 - d) Objects have holes
3. Robot manipulators can handle objects
 - a) With direct contact
 - b) Without direct contact
 - c) In hazardous environments
 - d) With high precision

Conclusion

This curricula consist of five topics where four of them are for vocational level and one for master level. The different topics have been tested with students during this project. A questionnaire have been filled in by students giving feedback on the tasks. One outcome from this is that the material needs to be used together with some lecture where the material and task are presented for the pupils. The level of this lecture should be set by the responsible teacher as this person have the knowledge about the students capability. Another conclusion is that the setup of the environment with right versions of programs have to be done well in before so the computers the students will use are fully working.

