DIGITIZING PRODUCTS:
CREATING DEMONSTRATORS
FOR FUTURE EDUCATION

Focus Project Demonstrator

Demonstrator classification and documentation

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Project consortium

Dissemination level

Code	Access granted to	
PU	Public	PU
PP	Restricted to other programme participants (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Legal Disclaimer

About the DigiDemo project

Environmental challenges and digital transformation are two of the main drivers changing the world and the way business will be is done in the future. Therefore, it is essential to enable future employees to address these drivers. The skills and competences needed to develop digitalized products and awareness of the environmental challenges are therefore crucial for the European workforce and industry to continue being competitive in a future green economy and to maintain jobs across Europe.

The DigiDemo project addresses these challenges by developing demonstrators especially for higher education allowing to improve mainly mechanical engineering studies by integrating skills and competences allowing them to understand, develop and commercialise connected products. The results will be publicly available and can be used by every institution interested in integrating this type of training in their cursus.

1 Contents

Document authors

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Revision history

Version	Date	Author(s)	Description
1.0	2021-10-21	Raphael Schönberger	Initial draft
1.1	2023-03-06	Horatiu O. Pilsan	Added sustainability educational information and did some minor corrections
1.2	2023-05-26	Robert Amann	Cross-references update

Document status

Status description
Final Version

Abbreviations

ESTA	ESTA Belfort (France)
FHV	Fachhochschule Vorarlberg (Austria)
FiV	Fagskolen i Viken (Norway)
UCN	University College Nordjylland (Denmark)
UBB	Universitatea "Babes-Bolyai" din Resita (Romania)
PLC	Programmable Logic Control
GUI	Graphical User Interface
FMEA	Failure Mode and Effect Analysis
EMC	Eletromagnetic Compatibility
CAD	Computer Aided Design
PCB	Printed Circuit Board
FEM	Finite Element Method
UART	Universal Asynchronous Receive Transmit
SPI	Serial Peripheral Interface
ADC	Analog to Digital Converter

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1 Introduction

This demonstrator is named according to the course it is used in, the “Focus Project”. It is a pick-and-place handling setup similar to the ones commonly used in industry.

The main purpose is to have students from different disciplines and with different background to implement mechatronic products in teams by combining both mechanical engineering and electronics with PLC (Programmable Logic Control) programming and communication.

2 Overview

The key properties of the focus project are:

Table 1: Specification of key properties of the focus project

Key Property	Value
EQF level	6 (Bachelor)
Year of study	3
Domain	Mechatronics
Objective	Hands-on
Workload	10 ECTS
Keywords	Gantry robot, manipulator, stepper motor, pick-and-place, PLC

The focus project is part of a course in the 5th semester of the mechatronics undergraduate program at FHV. This semester is the exchange semester in which many of the students working in the project are from partner institutions. The typical class size is 20 – 25. Students are split into five teams of 4-5 people. The teams are mixed in several manners. Both exchange students (from different countries) and local students work in a team. Students are allowed to choose between two courses “focus mechanical engineering” and “focus electronic engineering”, depending on their interests. Students from both the mechanical and the electronic course work in a team. A gantry robot as can be seen in Figure 1 is given. X and Y axes are controlled by a Beckhoff PLC which is given too. The task of the students is to add a Z axis moved by a stepper motor controlled by an embedded system, build a gripper and a spinning top (to be picked and then placed) and some other parts needed. The details of the task are given below.

The students’ task is not only to design, implement and test the missing components, but also to set up a requirements specification document and to put all things together and make the mechatronic system running.

Details of the course organization can be found in the document “Course-Information.pdf” in the folder “10_Documents”. This document contains the information for the students at the beginning of the course.

For any open questions regarding the demonstrator please feel free to contact one of the authors:

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Figure 1: Two focus project setups in a typical lab environment

Task Description

The students' task is to build a manipulator that will package 4 spinning tops in a box with a lid. The lid will have a slot for a card, and the manipulator will put a stamp on the card. A brief overview of the task is given in Figure 2.

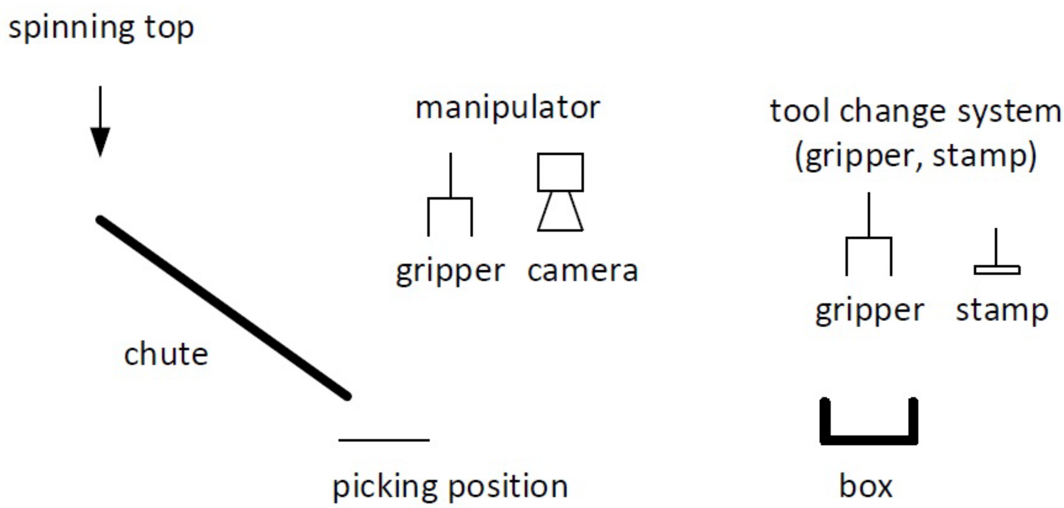

Figure 2: Brief overview of the task

Process Flow

- The operator must drop the first spinning top into a defined position on a feeding chute.
- The operator can drop the spinning top in any orientation, the top doesn't have to be upright when the operator drops it.
- The spinning top slides down the feeding chute towards the picking position and it realigns to become upright when it lands in the picking position.
- When the top cannot be realigned, it shall drop off the chute.
- The manipulator grips the spinning top at the picking position and places it in compartment 1 of the box.
- The operator drops the next spinning top.
- The process repeats, beginning with step 1, until the box is full.
- The manipulator closes the lid, changes the tool and stamps the card on the lid.
- A smart camera is used for checking the success of different process steps.

Packaging

- The picking position and casing (box) have to be in diagonally opposite positions on different heights.
- Minimum distance between picking position and box in X, Y and Z-direction: 300mm, 150mm, 50mm
- The manipulator realizes all movements with high speed.

Stamping

- The students design and manufacture a stamp which is used by the manipulator for stamping a card which is manually inserted in a slot of the lid.

Force Measurement

- The force in direction of the Z-axis has to be measured and displayed during the whole process.

Graphical user interface

- A graphical user interface (GUI) is used to: start and stop the process; show status of the machine; display force signal

Mechanical parts

Spinning top

The students construct a spinning top. The maximum diameter is 30mm and maximum height is 40mm.

Casing (box) with lid

- The students build a casing with a lid for packaging 4 spinning tops.
- The casing shall be able to hold 4 spinning tops in 4 separated compartments.
- The casing has a lid with a hinge.
- The lid has a slot for a business card.
- The casing shall be suited for assembly automation.

Feeding chute

- The students build a mechanical construction (without actuators) for delivering a spinning top.
- The spinning top is manually put down at a predefined position. The orientation of the spinning top is undefined.
- The feeding chute shall reorient the spinning wheel in a defined orientation and moves the part to the picking position.

Z-axis

- The students construct a Z-axis which is actuated by a stepper motor.
- The Z-axis uses a force sensor for measuring the forces in Z-direction during the hole process.
- The students use a dummy for the force sensor, which can be used for testing the system without force sensor.

Protector

- The students build a protector that can detect a crash before or during a collision of the tools.
- The protector is compliant in X and Y-axis.
- The protector sends a signal to the PLC which stops the movement.
- The protector can be mounted (or removed) within 1 minute.
- It shall be possible to replace the protector with a dummy in order to test the functionality beforehand or whenever it is removed.
- The dummy can also be mounted (or removed) within 1 minute.

Tools

- The students construct a tool 1 (gripper) for gripping spinning wheels.
- The gripper for grabbing the spinning wheels must not use an additional motor; using an electromagnet is allowed.
- The students construct a tool 2 (stamp) for stamping cards.

Tool change system

- The students construct a tool change system for changing tool 1 and tool 2 which uses snap connections. It is not mandatory that the students use a tool change system.

Mechanical Engineering

- Mechanical construction and manufacturing of all parts
- Most of the parts shall be manufactured with 3D printing (at FHV).

PLC Programming

- Sequence control
- Motor movements
- Monitoring of force
- GUI

Electronic Engineering

The movement of the Z-axis and the force measurement shall be realized with an embedded system:

- Design and manufacturing of a carrier board which connects the strain gauge signal amplifier and the motor driver and the RS232 level shifter.
- Design and manufacturing of voltage supply for the carrier board, because the carrier board is supplied from 24V DC and the supply voltages needed by the other boards must be generated.
- The maximum size of the carrier board is 100mm x 100mm.
- It is highly recommended (but not mandatory) that the students design and manufacture their own strain gauge signal amplifier and/or motor driver and/or RS232 level shifter.
- Microcontroller programming must include Z-axis-movement (SPI communication) and force measurement (AD-conversion) and communication (RS232) with the PLC.

Mechatronics

- Requirements analysis
- Writing requirements documents
- The result will be checked against the requirements documents
- Design, development, testing of the complete system

Image Processing

- A smart camera is used for checking the success of different process steps.
- The smart camera is triggered by the PLC (digital IO).
- A digital output of the smart camera is connected to the PLC for signaling the result of the visual check.
- Option: the smart camera sends further information (e.g. color of spinning top) to the PLC for visualization.

Figure 3 shows a block schematic of the focus project

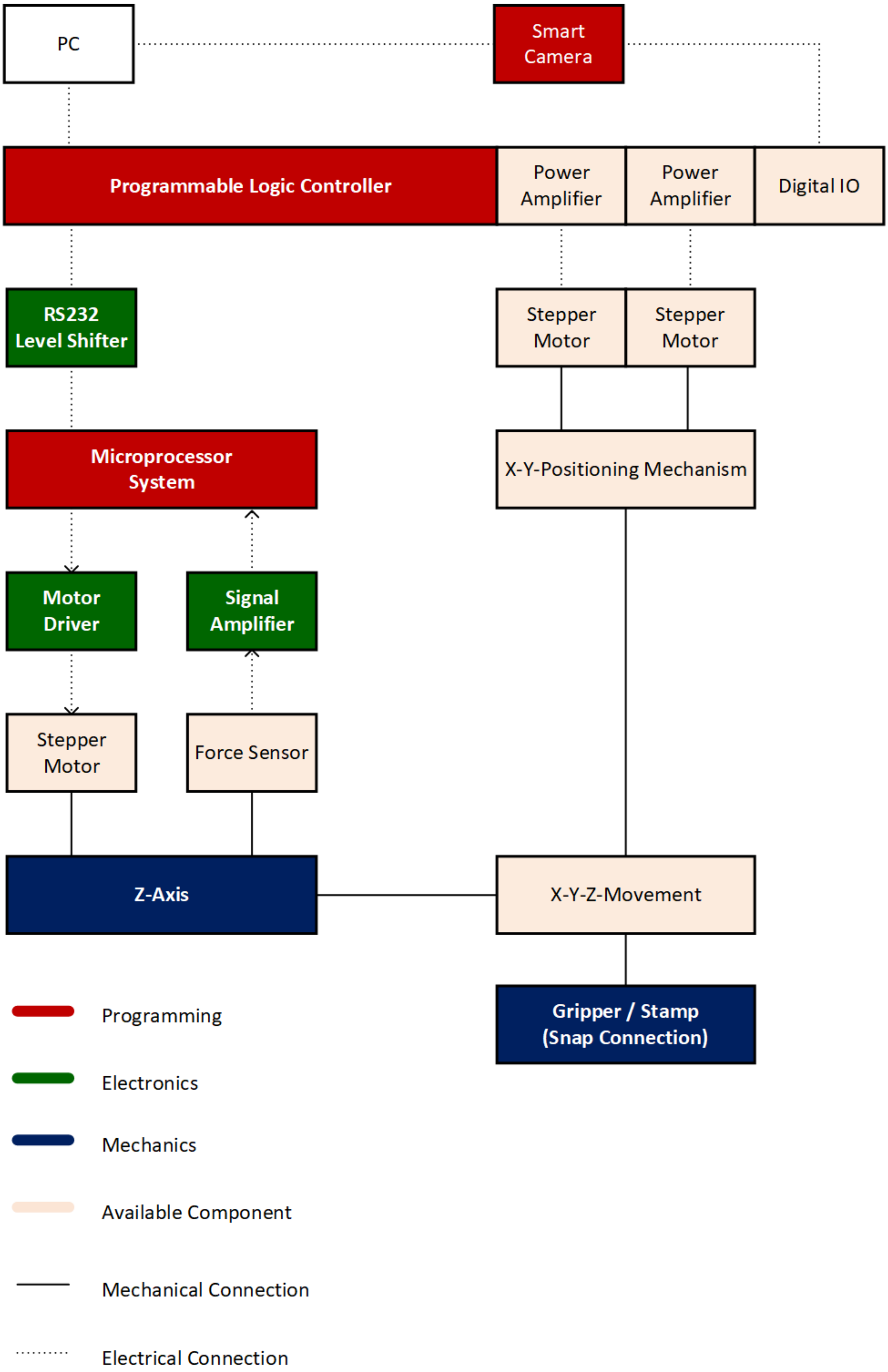

Figure 3: Block schematic of the focus project

3 Description of fulfilment of characteristics

The demonstrator fulfils the characteristics required as follows:

Table 2: Description of fulfilment of demonstrator characteristics for the focus project

Characteristic	Description
Teaching improvement	The focus project allows the students to go through the entire process of development of a mechatronic product starting with requirements, through design, implementation, test and integration of both mechanical and electronic components with software. They work in interdisciplinary teams.
Sustainability awareness	Sustainability awareness is not addressed explicitly in the demonstrator itself, but in the educational setting in which it is embedded. See chapter 5.3 for details.
Replicability	The demonstrator is implemented using off the shelf components, which are easy to replicate.
Industry needs	As the demonstrator is a gantry robot, lots of pick and place application in industry exist.
Interdisciplinarity	The demonstrator requires both electrical and mechanical engineers to cooperate in implementing a mechatronic system. Software components are also part of the project, both PLC and microcontroller programming.

4 Classification according to the dimensions

The demonstrator can be classified according to the dimension as follows:

Table 3: Classification of the focus project according to the dimensions

Dimension	Property	Value
Value chain	development	☑
	production	☑
	sales	☐
	after-sales-support	☐
	end-of-life	☐
Chain of technology	mechanical structure	☑
	sensors	☑
	electronic circuits	☑
	edge device	☑
	data transmission	☑
	cloud	☐
Sustainability	energy reduction	☑
	material reduction	☑
	better materials	☐
	better production	☐
	reparability	☑
	recycling	☐
Physicality	physical setup	☑
	simulation	☐
Degree of student freedom	demonstrated	☐
	guided	☐
	coached	☑
	autonomous	☐
Transportability	fixed	☐
	transportable	☑
	portable	☐
Costs (implementation)	EUR	7500
Costs (operation)	EUR	100
Workload (implementation)*	Hours	150

Dimension	Property	Value
Workload (operation)*	Hours	8
Size	m	0.9 x 0.65 x 0.7
Weight	kg	50
Special requests	no/yes, if yes: which	no

* The workload refers to the effort needed by the teacher for implementation and operation of the demonstrator. As for the workload of the students please refer to chapter 5.

5 Educational information

The focus project is the core of two courses. The students enrolled in the Mechatronics undergraduate program can choose among “Focus Electronic Engineering” and “Focus Mechanical Engineering”. Both courses have a workload of 18 ECTS credits and a total of 120 contact hours, both for teaching and coaching.

Mixed teams are set up to work together on the focus project. The workload for the project itself is 10 ECTS credits. The courses prepare the students for the project work and take place in advance, respectively while the students set up the requirements specification document.

The ECTS descriptions of the two courses are given below based on FH Vorarlberg (2020a) and FH Vorarlberg (2020b).

5.1 Focus Electronic Engineering

Prerequisites and co-requisites

Analysis of electronic circuits with passive components (R, L, C) and active components (transistors, operational amplifiers)

Selection and dimensioning of electronic circuits

Working with data sheets (electronic components, microprocessors)

Measurements on electronic circuits with multimeter and oscilloscope

Basic knowledge of structured programming

Basic knowledge of the mode of operation of microprocessor systems

Basic knowledge of the mode of operation of microcontroller peripherals

(e.g. serial interface, timer/counter, A/D converter)

Basic knowledge of the C programming language (ability to solve a problem autonomously by implementing a program using microcontroller peripherals)

Course content

Requirements analysis: determining requirements, documenting requirements, checking and reconciling requirements, requirements management, systems development life cycle, SysML

Programmable Logic Controllers: automation pyramid, PLC versus microcontrollers, PLC versus soft PLC, function of a controller, introduction to IEC61131-3, applications, security

Practical aspects: industrial volume products, standards, risk analysis (FMEA), thermal management, protection circuits, EMC - design guidelines, reliability

E-CAD and E-manufacturing: electronic systems and components, methods for describing electronic systems and components, packaging, tools (overview), types of circuit, information coding, measurement circuits, communication, digital interfaces, signal interfaces, circuit design and PCB layout, manufacturing and assembly of electronic components.

Learning outcomes

The students can determine and document requirements.

The students can program a sequence control in the PLC programming language Structured Text.

The students can describe the process of risk analysis.

The students can apply selected best practices and design guidelines for thermal management, protection circuits, EMC and further selected topics.

The students can read and apply data sheets and application notes for electronic circuits.

The students are able to design simple circuits for power electronics (H-bridge) and measurement technology (instrument amplifier).

The students are able to design PCB prototypes considering the most important layout design rules.

The students can program a microcontroller (digital IO, ADC, SPI communication, UART communication).

Planned learning activities and teaching methods

Lectures, project work, coaching sessions

Assessment methods and criteria

Written examination, technical documentation, project result.

Recommended or required reading

Clements, Alan (2006): Principles of Computer Hardware. 4. Edition. Oxford: Oxford University Press.

Microchip Corporation (2013): Application Note Atmel AT03665: ASF Manual (SAM D20). Online: http://ww1.microchip.com/downloads/en/DeviceDoc/Atmel-42139-ASF-Manual-SAM-D20_Application-Note_AT03665.pdf (accessed: 25.03.2021).

John, Karl-Heinz; Tiegelkamp, Michael (2010): IEC 61131-3: Programming Industrial Automation Systems: Concepts and Programming Languages, Requirements for Programming Systems, Decision-Making Aids. Berlin Heidelberg: Springer-Verlag.

Demant, Christian; Streicher-Abel, Bernd; Garnica, Carsten (2013): Industrial Image Processing: Visual Quality Control in Manufacturing. Berlin: Springer.

Karolina Zmitrowicz (2014): Requirements Engineering. Online: https://leanpub.com/requirements-engineering (accessed: 25.03.2021)

Mode of delivery (face-to-face, distance learning)

Face-to-face

5.2 Focus Mechanical Engineering

Prerequisites and co-requisites

Design of simple mechanical components

Knowledge CAD-software Siemens NX

Design of parts, assemblies, parts lists, drawings, fully dimensioned drawings according to standard

Course content

Requirements analysis: determining requirements, documenting requirements, checking and reconciling requirements, requirements management, systems development life cycle, SysML

Programmable Logic Controllers: automation pyramid, PLC versus microcontrollers, PLC versus soft PLC, function of a controller, introduction to IEC61131-3, applications, security

CAD: snap connections, manipulators, CAD

FEM: computer aided engineering, principle of the finite element method, types of structural analyses, function of structural analyses, finite element analyses, procedure, adjusting the geometry, boundary conditions, element types, material, mesh, common mistakes in modeling.

Learning outcomes

The students can determine and document requirements.

The students can program a sequence control in the PLC programming language Structured Text.

The students can design and manufacture a simple manipulator.

The students can apply the FEM (finite element method) to a mechanical structure.

Planned learning activities and teaching methods

Lectures, project work, coaching sessions

Assessment methods and criteria

Written examination, technical documentation, project result.

Recommended or required reading

Budynas, Richard G.; Nisbett, J. Keith; Tangchaichit, Kiatfa (2015): Shigley's mechanical engineering design. Tenth. New York: McGraw-Hill Education.

Zienkiewicz, Olgierd C.; Taylor, Robert L.; Zhu, J. Z. (2006): The finite element method: its basis and fundamentals. 6th edition. Amsterdam: Elsevier Butterworth-Heinemann.

John, Karl-Heinz; Tiegelkamp, Michael (2010): IEC 61131-3: Programming Industrial Automation Systems: Concepts and Programming Languages, Requirements for Programming Systems, Decision-Making Aids. Berlin Heidelberg: Springer-Verlag.

Demant, Christian; Streicher-Abel, Bernd; Garnica, Carsten (2013): Industrial Image Processing: visual quality control in manufacturing. Berlin: Springer.

Karolina Zmitrowicz (2014): Requirements Engineering. Online: https://leanpub.com/requirements-engineering (accessed: 25.03.2021)

Mode of delivery (face-to-face, distance learning)

Face-to-face

5.3 Sustainability – questions for reflection

The questions below are meant as inspiration for the teacher using the demonstrator. The aim is to strengthen the student's awareness regarding sustainability through reflecting upon questions related to the demonstrator. The questions can be used during the lecture or as the starting point for individual or group work, connected to the lecture. It is suggested that the students in groups answer the questions and then present the result of the discussion on class.

The questions below are divided into three main categories, general considerations, recycling, and product integrity, where the last two categories are addressing this specific demonstrator.

General considerations

- Does the making or use of the product create pollution?
- How can the energy consumption of the demonstrator be reduced?
- How can the material consumption needed for the demonstrator be reduced?

Recycling

- Can the demonstrator, or parts of it be recycled?
- Can all the materials be recycled – are they "pure" or do they need special treatment?
- How can the recycling of the demonstrator or its parts be improved?

Product integrity

- Which parts of the demonstrator need maintenance?
- Can parts which should be maintained be easily disassembled from the demonstrator?
- Can an update of components (which?) be foreseen to enlengthen its lifespan?
- Is the software of the demonstrator easy to update?

6 Organizational information

For the organization of the project the following apply:

- Project duration: the project spans an entire semester, starting in the first days of September and ending mid-December with the final presentations.
- Team size: The project teams are mixed (both electronically and mechanically interested students) and the optimal size is of 4 – 6.
- Preparatory and follow-up activities. No special activities are needed. Prior to the start of the project the demonstrators must be set up and checked by a lab technician. After project completion the mechanical parts added by the project groups will be removed.

7 Description of the technology and the setup

7.1 Demonstrator Documentation

There is no manual or background information on the rationale of the demonstrator.

The overview of the files supplied together with this description of the demonstrator is given below. It includes all files (e.g. CAD files, electrical drawings) needed to replicate the demonstrator.

File Structure:	**Focus-Setup**		
	Filename/Folder	Comment	Software
00_Notes			
	FileStructure.xlsx	Description of the files = this document	
	Price_Calculation.xlsx		
01_Pictures			
10_Documents			
	Course-Information.pdf	General information about the course for the students	
20_ExportImport			
30_AdditionalEquipment			
	Component-Overview	File with an overview of all additional components needed	
	3ChannelEncoder	Datasheets of the encoders used for the X- & Y-Axis	
	LinearModule	Datasheets of the linear module of the Z-Axis and the shaft guidance	
	Microcontroller	Datasheets of the microcontroler	
	RS232LevelShifter	Datasheets of the additional RS232LevelShifter	
	SmartCamera	Datasheets & guide of the SmartCamera Omron MicorHAWK	
	StepperMotors	Datasheets of all motors X-, Y- & Z-Axis	
	StepperMotorBoosterPack	Datasheet of the stepper motor boosterpack	
40_Simulation			
50_CAD			
	Portal_Manipulator_new.prt	Total assembly of the project	Siemens NX
60_ElectricalLayouts			
	FOCUS_XY-Mechanik.elk	EPLAN electrical layout project file	Eplan
	FOCUS_XY-Mechanik.pdf	Electrical layout of the project	
70_Programming			
	PLC\BasePrj	Base project of the PLC	
	PLC\Documents	Additional documents for the PLC programming	
	PLC\Libs	Libaries and external FB´s for the PLC programming	

Figure 4: File overview of the focus project documentation

7.2 Price Calculation

Details of the price calculation can be found in the table below:

Table 4: Price calculation of the focus demonstrator

Quantity (Unit)		Description	Price (per Unit)		Price (total)
7	m	Item Aluminium Profile 8 (40 x 40mm)	21	€/m	147
1	pc	Steelplate 600 x 800 x 12mm	400	€/pc	400
15	pc	Aluminium Parts (CNC Milled)	40	€/pc	600
2,5	m	Linear Axle	10	€/m	25
4	pc	Linear Bearing	60	€/pc	240
3	pc	Perspex (600x400)	10	€/pc	30
3	pc	Toothed Belt drive	60	€/pc	180
1	m	Energy Chain	50	€/m	50
1	pc	Linear Module Z-Axis	50	€/pc	50
1	pc	Force Sensor	200	€/pc	200
1	pc	Smart Camera	2700	€/pc	2700
3	pc	Steppermotor	50	€/pc	150
2	pc	3 Channel Encoder	90	€/pc	180
1	pc	Microcontroller Board Atmel	60	€/pc	60
1	pc	BOOSTER PACK DRIVER	25	€/pc	25
1	pc	RS232 SHIFTER	15	€/pc	15
1	pc	PLC CPU (CX5130-0175)	900	€/pc	900
1	pc	PLC C-Flash Card (CX2900-0026)	70	€/pc	70
1	pc	PLC Card (EL1859)	60	€/pc	60
1	pc	PLC Card (EL6001)	175	€/pc	175
3	pc	PLC Card (EL7041	245	€/pc	735
1	pc	PLC Card (EL3351)	150	€/pc	150
1	pc	small Material (Screws, Wire, Clamps)	500	€/pc	500
					7642

References

FH Vorarlberg (2020a). Focus electronic engineering course description. https://www.fhv.at/en/studies/engineering-technology/bachelorstudiengaenge/mechatronics-full-time-bsc/information-on-educational-components/semester/course/?stg=2009&typeEN=&sem=3&lv=59469&cHash=37b3ddc102e49a28b7b4e13c6b93a456 (accessed 2020-01-04)

FH Vorarlberg (2020b). Focus mechanical engineering course description. https://www.fhv.at/en/studies/engineering-technology/bachelorstudiengaenge/mechatronics-full-time-bsc/information-on-educational-components/semester/course/?stg=2009&typeEN=&sem=3&lv=59470&cHash=e245586c6a9e650e52815e8802ddf5c8 (accessed 2020-01-04)