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Context

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1 Executive summary

WP 2.2 details the learning materials of the Advanced Industrial Informatics Specialization Modules (AIISM) related to the module “Microcontroller based systems for controlling industrial processes”.

The contents of this package follows the guidelines presented in the USTUTT’s documentation of the WP 1 (Microcontroller based systems for controlling industrial processes)

- The PBL methodology was presented in WP 1.1
- The list of the module’s chapters and the temporal scheduling in WP 1.2
- The required human and material resources in WP 1.3
- The evaluation in WP 1.4

There was a change in the topic of the mini-project in contrast to the deliverable 1.2. It was planned originally to make a mini-project with a liquid-tank system. The new mini-project deals with a model-plant, producing letterpresses (see chapter 6). The task of controlling a liquid tank is used as a real-world task-setting for the labs.

Section 2 introduces the course and the outlines. Section 3 details the lecture, divided in subsections for each chapter. Section 4 describes the labs. There is a special subsection for each chapter. There are detailed powerpoint-files for each lecture and each lab, added as appendix. Section 5 gives an overview to the seminars. Each seminar has its own subsection. Finally section 6 details the Mini-project, and section 7 lists the bibliography and the references.

2 Introduction

The overall schedule of the whole course is presented in the following table. The course is designed for a total duration of 15 weeks. The workload for the students is 180 hours. Each week the students are in class for 4.5 hours. They listen the lectures and seminars, they attend the lab and they work on their mini-project.

About 0.75 to 1 hour in average there is a lecture for the students each week. This is mainly a presentation with slides. Another hour in average a seminar is given. A group of students prepares a special topic and presents it in a presentation of about 30 minutes. After that a discussion of 30 minutes will follow.

Approximately 1.5 to 2 hours the students solve problems in the lab. There are work orders for the students they have to solve. A tutor supports the students.

The last hour is for the students to work on their mini-project. The tutor can answer questions if necessary. There are another 5.5 hours homework on the mini-project per week. The students work on their own in their teams.

To prepare the final exam 30 hours are calculated for the students.

Chapter	Type	Topic	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	INTRODUCTION																
1	Lecture	Introduction to microcontrollers; architecture of microcontrollers	x	x													
1	Seminar #1.1	Overview of microcontrollers		x													
1	Lab #1.1	Development environment; connection of microcontroller to PC	x	x													
1	Lecture	Introduction to Process Control and mini project			x												
1	Seminar #1.2	C programming basics			x												
2	PROJECTMANAGEMENT																
2	Project	Formal specification of the mini-project			x												
2	Project	Analysis of project specification				x											
2	Seminar #2.1	Project managment				x											
2	Project	Project planning, management and timetable of mini-project					x										
2	Project	Design of mini-project					x										
2	Seminar #2.2	Discussing mini-project status										x					
2	Seminar #2.3	Project documentation strategies												x			
3	I/O-SYSTEM of microcontrollers																
3	Lecture	Digital I/Os of microcontrollers				x											
3	Lab #3.1	Digital I/O				x	x										
3	Lecture	Analog I/Os of microcontrollers					x										
3	Lab #3.2	Analog I/O					x										
3	Lecture	Amplifier circuits for actuators and sensors						x									
3	Lab #3.3	Build up a basic amplifier circuit						x									
3	Seminar #3.1	Libraries						x									
3	Lecture	State machines, scheduling							x								
3	Seminar #3.2	Software tools for modeling of state machines							x								
3	Project	Using libraries in the mini-project							x								
4	TIMER AND INTERRUPT HANDLING																
4	Lecture	Timer Handling								x							
4	Lab #4.1	Basic timer functions								x							
4	Project	Implementing digital I/O							x								
4	Lecture	Interrupt handling									x						
4	Lab #4.2	Basis interrupt functions									x						
4	Project	Implementing analog I/O								x							
5	GRAPHIC SYSTEM																
5	Lecture	Displays and graphic routines										x	x	x			
5	Lab #5.1	Basic Display functions										x					
5	Project	Implementing state machine and controller									x						
5	Lab #5.2	Advanced display functions											x	x			
5	Project	Implementing display											x				
5	Project	Implementing user interface											x				
6	COMMUNICATION between microcontrollers																
6	Lecture	Communication between different microcontrollers												x	x		
6	Lab	Basic communication methods (Serial)												x			
6	Project	Communication to other liquid tanks												x	x		
6	Lab	Advanced Communication Methods													x		
7	CONTROL METHODS																
7	Lecture	Closed Loop Controller: modeling and algorithms													x	x	
7	Lab	Programming closed loop controllers													x	x	
8	INTEGRATION AND VALIDATION																
8	Project	Module integration and documentation of the mini-project.														x	
8	Seminar #8.1	Test and validation strategies														x	
8	Project	Test and validation of the project; documentation of the mini-project															x

3 Lecture

A lecture is the first step in the learning process for each of the topics in a module. The lecturer presents the main topics, basic knowledge and the structure of the contents. This includes some application examples.

The course is divided in eight chapters (see schedule in WP 1.2). This section is divided into subsections for each chapter.

3.1 Chapter 1: Introduction

Chapter 1 focuses on an introduction to microcontrollers, sample Applications, definition of Basic concepts and important terms. After a classification of control technology, an overview on the structure and Components of a Control system is given. An overview on types and architecture of microcontrollers, followed by the basics of process control in industry close chatpter 1.

There is a set of slides (power-point-presentation Chapter 1.pptx) for giving the course.

3.2 Chapter 2: Projectmanagement

Chapter 2 deals with project-management. There is no lecture for this topic, as it is not the main focus of this course. The contents of this chapter are worked out by seminars about project management methods (seminar #2.1, discussions about the mini-project (seminar #2.2) and project documentation strategies (seminar #2.3, see section 5 of this document). In addition the students learn directly by developing the mini-project.

3.3 Chapter 3: Input-/Output-system of microcontrollers

Chapter 3 focuses on the I/O-system of microcontrollers. The interfaces of the microcontroller interact with the process directly. There are sensors and actuators to measure and influence the industrial process. The chapter introduces the different kinds of input- and output-signals: digital signals and analog signals. It shows how technical sensors and actuators are connected to the microcontroller. Often there are amplifier- or adaption circuits necessary. All input-output-concepts are detailed by examples and their programming in the microcontroller. The chapter is closed by an overview about scheduling mechanisms and state machines.

There is a set of slides (power-point-presentation Chapter 3.pptx) for giving the course.

3.4 Chapter 4: Timer and interrupt handling

Chapter 4 introduces timer and interrupts. Timing functions are very important for controlling industrial processes. You have to monitor the right schedule for industrial processes, log variances in time and influence the process at certain moments.

Some tasks are very time critical and need an immediate reaction. Interrupts help solving such problems. The normal flow of the program is paused and a special interrupt service routine is performed. In addition this chapter deals with the concepts of programming timer and interrupts using the microcontroller Arduino Due.

There is a set of slides (power-point-presentation Chapter 4.pptx) for giving the course.

3.5 Chapter 5: Graphic system

Chapter 5 deals with graphical user interfaces for microcontrollers. The user of a control system wants to see the current status of the industrial process and wants to influence the industrial process. At first different types of user interfaces and user interaction are introduced. The main part of this chapter focuses on a graphical TFT-display wired to the microcontroller Arduino Due. In detail the necessary libraries and functions are explained. Various examples support the programming of the graphical display in C-language.

There is a set of slides (power-point-presentation Chapter 5.pptx) for giving the course.

3.6 Chapter 6: Communication between microcontrollers

Chapter 6 gives a short introduction to concepts of communication between microcontrollers. There is a complete module (#4 Industrial Networks and Fieldbusses) dealing with this topic. This lecture focuses on special communication mechanisms used with microcontrollers.

Existing libraries for the arduino microcontroller are introduced. Examples show the programming of basic communication mechanisms in C-language.

There is a set of slides (power-point-presentation Chapter 6.pptx) for giving the course.

3.7 Chapter 7: Closed loop Control

Chapter 7 introduces algorithms of closed loop control. Key feature of closed loop control is the recirculation of a current value and comparison with a desired value. Based on this result the system is influenced to minimize the measured difference. There are different types of controllers – their mathematical models will be explained, combined with advantages and disadvantages of the different methods.

After that basic control algorithms are programmed in C-language for their use on the microcontroller Arduino.

There is a set of slides (power-point-presentation Chapter 7.pptx) for giving the course.

3.8 Chapter 8: Integration and validation

Chapter 8 deals with the integration and validation of the mini-project. There is no lecture for this topic. The contents of this chapter are worked out by a seminar about test and validation strategies. In addition the students learn directly by developing the mini-project and integrating and documenting their own mini-project.

4 Lab

The laboratory session (lab) is the first practical exercise that students take to acquire a basic set of skills related to the topic presented in the lecture. The exercises in the lab solve specific and well-defined problems; they are guided, fully documented, and of progressively increasing complexity. The lab provides students with a set of tools and skills that can be used to solve more open problems during the mini-project

4.1 Lab #1.1: Introduction to programming of Arduino microcontrollers

During the course Arduino Due microcontroller boards are used. There is a microcontroller-environment for every team of students. This environment consists of a personal computer or laptop, the programming environment, two microcontrollers Arduino DUE, a breadboard, displays and some electric components (LEDs, wires, resistors).

The objective of this lab is to get familiar with the use of the programming environment, the steps to write a C-program for the microcontroller and to transfer the program to the microcontroller. Simple applications show the concepts of programming.

There is a power-point-presentation (Lab#1.1.pptx) including the slides and work orders for the students.

4.2 Lab #3.1: Programming digital I/Os of Arduino microcontrollers

The objective of this lab is to get familiar with the use of digital I/Os of the Arduino Due microcontroller. This lab introduces the simulation environment for the other labs, too. The students write more complex C-programs for the microcontroller and learn the basisc of wiring the microcontroller. The model of the water tank is introduced, which is used by the other labs, too.

There is a power-point-presentation (Lab#3.1.pptx) including the slides and work orders for the students.

4.3 Lab #3.2: Programming analog I/Os of Arduino microcontrollers

The objective of this lab is to get familiar with the use of analog I/Os of the Arduino Due microcontroller. This lab deepens the work with the simulation environment and the basic example of the water tank is extended step by step. The students write more complex C-programs for the microcontroller and deepen the basisc of wiring the microcontroller.

There is a power-point-presentation (Lab#3.2.pptx) including the slides and work orders for the students.

4.4 Lab #3.3: Build up basic amplifier circuits

To influence industrial processes there are actuators like motors, valves or switches. There are LEDs to display the state of the process and there are sensors to acquire information from the industrial process. All of these elements must be wired to the microprocessor. Often it’s not possible to connect these elements directly to the microprocessor as it only can deal with low voltages and low currents. Amplifier and adaption circuits fix this problem. The objective of this lab to design some basic amplifier circuits.
There is a power-point-presentation (Lab#3.3.pptx) including the slides and work orders for the students.

4.5 Lab #4.1: Programming basic timer function of Arduino microcontrollers

The objective of this lab is to program timer functions for the Arduino microcontroller. As example the control system for a traffic light for a two way crossing is programmed. The students learn how to measure time and how to activate processes at a certain time.

There is a power-point-presentation (Lab#4.1.pptx) including the slides and work orders for the students.

4.6 Lab #4.2: Creating and Handling interrupts of Arduino microcontrollers

Interrupts are used to achieve immediate reactions to an event. This lab extends the control system for the liquid tank by time critical requirements. The students must use interrupts and timer functions to solve these problems. They deepen their knowledge in C-programming and designing more complex control tasks.

There is a power-point-presentation (Lab#4.2.pptx) including the slides and work orders for the students.

4.7 Lab #5.1: Programming of basic display functions on Arduino display

This lab deals with the graphical display of the Arduino Due. A TFT display with the graphic controller ILI9163 is wired to the microcontroller and a basic user interface is implemented on it. The students learn how to connect the graphic display and how to use the library functions for accesing the display. Based on this knowledge the students implement an easy graphical user interface for displaying the process state of the liquid tank.

There is a power-point-presentation (Lab#5.1.pptx) including the slides and work orders for the students.

4.8 Lab #5.2: Programming of advanced display functions on Arduino display

This lab deepens and broadens the knowledge of Lab 5.1. The students implement advanced display functions for the liquid tank. In addition to the status display of process variables the liquid tank should be operated by a simple graphical user interface. The students use a combination of graphical display and hardware buttons to control the liquid tank.

There is a power-point-presentation (Lab#5.2.pptx) including the slides and work orders for the students.

5 Seminar

During the seminars the students must solve problems on the topic of the lecture. The students work in teams of 4 students and get a special topic to prepare. They do internet research, collect data, classify these information, present it to the rest of the students, discuss as experts with the other students and prepare a written handout with the most important facts. The teacher supervises the group, gives advices and sums up the discussion. He provides additional information material if necessary.

There are several seminars throughout the whole course that address and deepen different topics of Microcontroller based systems for controlling industrial processes. The following list details the topics of the seminars and shows its places in the schedule of the course.

5.1 Seminar #1.1: Overview on microcontrollers

Seminar #1.1 deals with microcontrollers and is scheduled in week 2. The aim of the seminar is to give an overview on latest, relevant microcontrollers. Microcontrollers are the basis of the whole course and the students must know which kind of microcontrollers are available, how differ these microcontrollers, what are advantages/disadvantages of special types of microcontrollers and what are typical applications of these microcontrollers. The students learned about the classification criteria of microcontrollers in the lecture. They should pick these criteria and look for more detailed criteria to classify the big flood of available microcontroller types. There is a list of the most important microcontroller vendors (Altera, Atmel, Cypress, Freescale Semiconductor (Motorola), Infineon, Intel, Microchip, Texas Instruments) as a starting point for the students.

The students present their results in an oral presentation of about 30 minutes. They sum up their results in a written handout additionaly.

5.2 Seminar #1.2: Basics in C programming

Seminar #1.2 deals with the programming language C and is scheduled in week 2. The aim of the seminar is to prepare the basics in C programming. C is the most important programming language for microcontrollers. The students must bring basic knowledge in any programming language as a prerequisite to the course. The seminar should focus on the binary numbering system, logic operations (AND, OR, NOT, …), shift-operations, program sequences (loops, branches), the concept of functions and the methods of using pointers. There is a wide supply of teaching material for the programming language C – the special task is to reduce these information to the most important contents.

The students present their results in a presentation, supplemented by practical exercises with the microcontroller. They write a compact handout with the results of their seminar additionaly.

5.3 Seminar #2.1: Methods of project management

Seminar #2.1 deals with the project management and is scheduled in week 4. The aim of the seminar is to give an overview on proven methods of project management. The students must plan, organize, motivate and control resources, procedures and protocols to achieve the specific goal of the mini-project (see chapter 6). There are special methods, tools and representations of facts, dates and resources. The seminar should give an overview and explain a set of tools for managing the mini-project.

The students present their results in an oral presentation of about 30 minutes. They sum up their results in a written handout additionaly. This handout is the basis for all of the students to plan their mini-project.

5.4 Seminar #2.2: Status of mini-project

Seminar #2.2 focuses on the current status of the mini-projects and is scheduled in week 10. The aim of the seminar is to discuss the current status of each mini-project. Each team presents their current results, their schedule, their problems, ... The students exchange their ideas, help other students with problems they already solved and the subervisor gives feedback to the current results.

Each mini-project team gives a presentation of about 15 minutes about their current project status. After that a short discussion starts. At the end the supervisor sums up the results of the discussion.

5.5 Seminar #2.3: Project documentation

Seminar #2.3 deals with methods and strategies for project documentation and is scheduled in week 12. The aim of the seminar is to give an overview on proven methods and strategies of project documentation. The students must document their own mini-project (see chapter 6). There are special methods, tools and data-storage strategies for the project documentation. The seminar should give an overview and discuss a set of tools for documenting project in a team.

The students present their results in an oral presentation of about 30 minutes. They sum up their results in a written handout additionaly. This handout helps all of the students to document their mini-project effectively.

5.6 Seminar #3.1: Use of libraries

Seminar #3.1 explains the usage of programming libraries in the microcontroller environment and is scheduled in week 6. The aim of the seminar is to give an overview on useful libraries, their usage and their limitations. The seminar should focus on libraries for the Arduino Platform, for the usage of motors, busses, displays, real-time operating system functions (timer, interrupt, scheduler, semaphores, ...). The seminar should explain properties of libraries, linkage of libraries and construction of own libraries.

The students present their results in an oral presentation of about 30 minutes. They sum up their results in a written handout additionaly. This handout helps all of the students to use libraries in their mini-project and to know the most relevant libraries.

5.7 Seminar #3.2: Modeling of State Machines

Seminar #3.2 deals with software tools for modeling of state machines and is scheduled in week 6. The aim of the seminar is to give an overview on graphic-based and text-based software tool for the modeling of state machines and petri nets. The students can model the functionality of their applications in the labs and the functionality of their mini-project by state machines in a very clear and easy way. The seminar should explain software tools, show graphical user interfaces and possibilities of automatic code generation from a graphical layout of a state machine.

The students present their results in an oral presentation of about 30 minutes. They sum up their results in a written handout additionaly. This handout helps all of the students to use tools for state machines in their mini-project.

5.8 Seminar #8.1: Test and Validation Strategies

Seminar #8.1 deals with methods and strategies for software testing and validation and is scheduled in week 14. The aim of the seminar is to give an overview on proven methods and strategies of software testing strategies. The students must test the software of their own mini-project (see chapter 6). There are special methods and tools for software testing. The seminar should give an overview and discuss a set of tools for testing software in a project, taking teamwork into account.

The students present their results in an oral presentation of about 30 minutes. They sum up their results in a written handout additionaly.

6 Mini-project

During the mini-project students use the knowledge and skills that they have acquired in the lectures, laboratory sessions and seminars to develop the control-system for controlling a physical process in an integral way. The problem of the mini-project is the highest complexity problem in the course. The working teams in the mini-project are the same as in the seminars.

With the mini-project the students learn to integrate the tools and knowledge of the course to develop a simple but complex control system for an industrial process. Further they learn how to document and present the results of the mini-project.

6.1 Description of the mini-project

The team is responsible for the design, implementation, test and documentation of a plant for the production of individual letterpresses. The letterpresses consist of an aluminium cylinder (individual colour) with a hole in their middle. Into this hole an individual colored precious stone must be mounted. There are several machines available which have to be combined to a complete production system. The control system is based on a microcontroller.
Available production- and transport-systems:

- The product input "produces" aluminium cylinders (raw, without colour) and precious stones in different colours. The aluminium cylinders can already contain a hole or the hole has to be produced.
- As a transport system there are conveyor belts of different length. The length can be designed individually. Each conveyor belt is driven by a single motor. The motor can be adjusted in its speed by an analog signal (0-100%) and in its direction by a digital signal. The 100% speed is configurable.
- To bring the products from one conveyor belt to another conveyor belt that is arranged in a 90° angle or to stop products on the conveyor belt, there are pneumatically actuated pushers. The magnetic valves are actuatd by a digital signal (signal 0: pusher moves to its initial position and stays there, signal 1: pusher moves to its extended position and stays there.
- There are machines for different processing operations (drilling, painting, mounting). The machines must be placed on a continuous conveyor belt
- There is a machine for drilling holes into a raw aluminium cylinder. One aluminium cylinder must be fed to the machine (on one side). After 2 seconds (earliest) a digital signal (set to 1) can start the drilling process. The drilling process takes some time (approximately 4 seconds) and after finishing the drilling process the machine automatically provides the processed aluminium cylinder on the opposite site of the input of the machine.
- There are machines for colouring the aluminium cylinders. One aluminium cylinder must be fed to the machine (on one side). After 2 seconds (earliest) a digital signal (set to 1) can start the colouring process. The colouring and drying process takes some time (approximately 10 seconds) and after finishing the colouring and drying process the machine automatically provides the coloured aluminium cylinder on the opposite site of the input of the machine.
- For detecting the properties of a workpiece (aluminium cylinder, precious stone) there is a measuring machine. One workpiece must be fed to the machine (on one side). It takes 1 second to move the workpiece through the measuring machine. The workpiece is then automatically provided on the opposite site of the input of the machine. The machine delivers several output signals, which are valid until the next workpiece moves into the machine:
    - Signal ....
- There are photoelectric sensors which detect workpieces on a conveyor belt. The sensor delivers a digital signal. The signal is 0 if no workpiece is in front of the photoelectric sensor. The signal is 1 as long a workpiece is in front of the photoelectric sensor.
- For mounting the letterpresses there is an automatic mounting machine. One aluminium cylinder (with hole!) and one precious stone must be fed to the machine (on one side, one after the other). After 2 seconds (earliest) a digital signal (set to 1) can start the mounting process. The mounting process takes some time (approximately 1 second) and after finishing the mounting process the machine automatically provides the complete letterpress on the opposite site of the input of the machine. Supernumerary workpieces

(e.g. already one aluminium cylinder is in the machine and an additional aluminium cylinder is fed to the machine) are just moved through the machine within 1 second.

- The product output takes workpieces out of the system, for example for packaging.

6.2 Mini-project task-setting and constraints

Within the mini-project the students are supposed to solve a control-problem close to a real world project. The mini-project adresses the knowledge of the whole course and integrates it in a complex problem-solving. The students work in a team, which helps them learning to split tasks, to keep a schedule, and to work together.

The control-system for the production system must fulfill the following requirements:

- A letterpress must be assembeled automatically. The whole material flow must be done by conveyor belts.
- The product input "produces" parts randomly. The product output can take an unlimited number of workpieces.
- The user can give orders for letterpresses by a graphical user interface. The user interface gives status information about the production process and the material flow.
- The layout for the plant is limited to a grid of 10x10 fields. A machine has the dimension 1x1. Conveyor belts are only allowed in horizontal and vertical direction. The dimensions are Nx1 or 1xN (N: integer).

The students must fulfill the following tasks:

- Task 1: Functional specification: The students analyse the requirements to the desired machine and write a functional specification.
- Task 2: Project plan and schedule: The students analyse the project and their functional specification and derive a project plan with work phases, milestones and a schedule. The available human ressources are planned and assigned to tasks.
- Task 3: Plant layout: Based on the functional specification the students derive a plant layout. It contains the necessary machines, conveyor belts, sensors, product input and product output.
- Task 4: Software specification: The students decompose the complete functionality to capsuled modules and use methods of object oriented development and object oriented programming. A reuse of software modules should be possible.
- Task 5: Sensor-Actuator-List: The students define a list of all necessary sensors and actuators, including their connection to the control system (input-/output-signals).
- Task 6: Software Implementation: The students implement the software for the control-system. The control-system is based on an microcontroller "Arduino DUE", programmed in the programming language "C".
- Task 7: Test: The students test their software and make protocolls of their test cases. For testing the software a simulation system is available. This simulation system is also based on a microcontroller "Arduino DUE". It simulates the complete behaviour of the production system. The students must configure this system with their plant layout and electrically connect their input- and output signals to the simulation system.
- Task 8: Documentation: All phases of the project must be documented. Each milestone must be presented in a presentation to the supervisor.

6.3 Scheduling of the mini-project

The overall workload of the mini-project for a team of 4 students is approximately 360 hours. The team is under supervision of a teacher in the laboratory for 1,5 hours per week averaged (15 weeks). The rest of the time the students work on their own.

The mini-project starts in week 2. In parallel to the progress of the lectures and seminars the students work on the different tasks of their mini-project. The final presentation is given in week 15, together with a complete set of documents.

One main task of the mini-project is the planning of the project, so in this chapter only a rough schedule is given.

Task	Type	Topic	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	MINI-PROJECT																
1	Project	Functional specification of the mini-project		x	x												
2	Project	Procet plan and schedule			x	x											
3	Project	Plant layout				x											
4	Project	software specification					x	x	x	x	x						
5	Project	Sensor-Actuator List					x										
6	Project	Software Implementation								x	x	x	x	x	x		
7	Project	Test and Evaluation														x	x
8	Project	Documentation		x	x	x	x	x	x	x	x	x	x	x	x	x	x

7 References

www.arduino.cc, Webseite des Arduino-Projektes

Vorlesung STmA, ISW, Vorlesungsunterlagen

Vorlesung AT I, IAS, Vorlesungsunterlagen