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1 Executive summary

This section of workpackage WP 1.2 details the learning activities of the Advanced Industrial Networks and Fieldbuses Module (AINFM).

The AINFM is structured in different activities of progressive complexity, culminating in a final mini-project where the students will use the new knowledge acquired to develop a complete networked control application. The learning sessions are organized in these activities: lectures, seminars, laboratories, mini-project and tutorship.

In this deliverable, the structure, learning activities, prerequisites and schedule for the Advanced Industrial Networks and Fieldbuses Module are provided.

2 Introduction

Similarly to other courses in this project, the methodology used is mainly based on problem based learning (PBL) and other accepted active learning techniques with the intention of creating a realistic working environment which the student will experience in his future career. This model is based on the educational goals proposed by the Accreditation Board for Engineering and Technology (ABET) [1] and different experiences [2-5]. The general aims of the approach are:

- To guarantee that the student acquires knowledge regarding the fundamentals of the specialization.
- To encourage the students to work as part of a team in solving industrial problems.
- To encourage students to apply practical skills in order to improve their problem solving abilities in the situations they will meet in their working environment.
- Due to the rapid advances in this area, to develop the capacity to adapt to any new networking technologies with which he may come into contact in the future.

Taking into account this methodology, all the learning activities are driven around two specific communication technologies, integrated within the control of two industrial processes. The choice of these two industrial processes permits the course to cover both of the main types of industrial processes, namely continuous and discrete control processes. The final mini-project for this module will consist on the networked control of one of these two processes.

The choice of the two industrial communication networks allows the student to become acquainted with examples of networks used at the field level, as well as in the networks commonly used at the company level of the control hierarchy[12].

In order for the student to fully profit from the learning activities, we provide a list of prerequisites in the form of background knowledge and required skills that the student is expected to fulfil before beginning the activity.

3 Pre-requisites

These are the pre-requisites for this module:

- Basic C programming
- Basic micro-controller programming
- Basic programming on POSIX operating systems

- Basic digital and analog electronics

4 The Manufacturing Cell Model

The specification, design, implementation and validation of communication protocols for both process control, as well as for process supervision by higher layers in the control hierarchy, is taught using a model of a discrete process manufacturing cell [15]. The model consists of a multi-platform software application that simulates the storage, transport, and processing of work pieces, where the simulated sensors and actuators are accessible over a Modbus/TCP communication protocol.

The model includes conveyors that transport the work pieces, milling machines that transform these same work pieces, pushers used for sorting, as well as 3D manipulators and automatic warehouses. The simulation software is highly configurable through a simple configuration in textual format; the number and position on the plant floor of each conveyor, machine, manipulator, pusher and warehouses is set in the configuration file, as are other properties such as conveyor speed, and the transformations made to work pieces on each milling machine / milling tool pair. It is therefore possible to simulate very simple manufacturing cells, as well as very complex manufacturing lines consisting of several manufacturing cells.

Control of the machinery on the plant floor (eg. conveyors, milling machines, pushers, etc.) is made by controlling the state of several boolean variables, and feedback is provided by reading simulated boolean sensors. A simple conveyor, for example, has two actuators (one motor for moving in each direction), and one sensor (senses a work piece on the conveyor). More complex machines (e.g.: 3 axis portal robot, milling machine, rotating conveyor, sliding conveyor) have many more actuators and sensors.

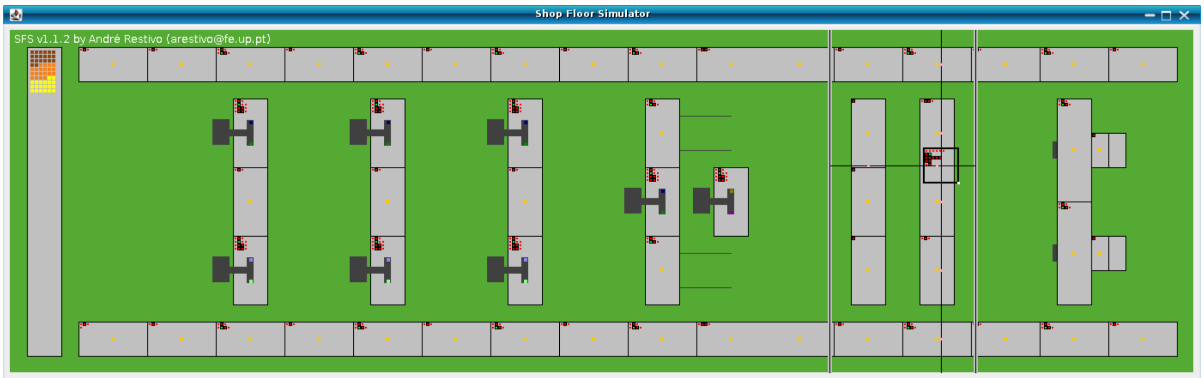

Figure 1 Manufacturing Cell Simulator

5 Module decomposition

Industrial informatics systems are usually organized in a hierarchical fashion [6-10, 12]. The lowest layer (layer 0) consists on the physical equipment in the production process to be automated, including both the mechanical and electrical components. The equipment in layer 1 provides the interface to the mechanical components of layer 0, and is typically composed by sensors and actuators. At this level either no control logic is executed, or very simple logic is used typically to implement safety interlocks (e.g. if protection gate is opened, switch off motor), or direct speed control of motors (eg. inverters, or speed drives).

The logic that is usually considered the automation of the process is executed at layer 2. Typical equipment at this level are PLCs (Programmable Logic Controllers), DCS

(Distributed Control Systems), SCADA (Supervision, Control And Data Acquisition), or industrial computers executing either a SoftPLC package or more complex control algorithms such as batch recipe execution [11].

Layer 3 is dedicated to the management of manufacturing operations (eg. dispatch, detailed production scheduling, production tracking, etc.), as is typically executed on computers (PCs or workstations) running MES (Manufacturing Execution System) software packages. The highest layer 4 consists of the business logistics (eg. plant production scheduling, shipping, inventory control, etc.). It is mostly at this layer that the well known SAP [13] and SSA/Infor [14] commercial software packages operate.

In order for these layers to work fluidly together, they need to exchange data between the devices in the same layer, as well as devices between each pair of layers. This module will focus mainly on the networks used inside layers 1 and 2, as well as those used to interconnect layers 1 to 2.

Since the course follows a PBL approach, each chapter will focus on a specific technology used in industrial communication. This technology will be approached as a possible solution for a specific communication requirement in a distributed control application. Nevertheless, taken together, these modules will allow the student to go beyond the specific technologies, and to understand the issues at stake in industrial communication networks.

For example, chapters 2 and 4 (Modbus/TCP and Modbus/RTU) will allow the students to understand the layered approach to industrial networks, as the same high level protocol will be used on distinct physical layers, as well as distinct devices (industrial computer, and micro-controller). The first of these will focus on how to implement and use the Modbus protocol over TCP/IP networks. The second will extend the Modbus protocol to serial communication networks (RS232 and RS485). RS232 will be used for communication between industrial computers, as well as between these and a micro-controller.

Chapters 5 and 6 will focus on CAN networks. This network was chosen as it uses an interaction model based on the publish/subscribe interaction model, which is distinct to the client/server and master/slaves models used in Modbus/TCP and Modbus/RTU respectively. The layered approach to communication protocols will once again become evident when the CANOpen protocol is partially implemented over CAN.

6 Learning activities

Based on the previous high level structure, a more detailed organization of the module, divided into 7 chapters, is proposed.

1 Introduction
2 Modbus/TCP
3 Discrete Event Control
4 Modbus/RTU
5 CAN
6 CAN Open
7 Hierarchical Control

Chapter 1 introduces the field of industrial communication networks, and provides an overview of how these are organized.

Chapter 2 is dedicated to the second section of the module – Modbus/TCP. This is a protocol typically used between devices of layer 2, and the learning activities will focus on a hands on approach of implementing the protocol, and some very basic tests with the manufacturing cell model.

The following 2 weeks will focus on control strategies for discrete event systems, and will provide the students with an oportunity to start developing the control application for their miniproject.

Chapter 4 focuses on the RTU and ASCII versions of the same Modbus protocol. These protocols are commonly used to interconnect devices on ISA95 layers 1 and 2. For this reason, the practical implementation work will focus on the interaction between a computer and a micro-controller, both using this protocol.

Chapter 5 is dedicated to another protocol commonly used to interconnect devices in layer 1 to those of layer 2. This CAN protocol mostly covers the 2 lower layers of the OSI model, therefore most of the implementation effort will go towards getting two micro-controllers to exchange very basic and simple data frames.

Once a working CAN network has been built, the students will spend the following 3 weeks studying the CAN-Open protocol. This protocol works over the CAN bus, but adds a relatively complex application layer based on objects, and with distinct device profiles for distinct types of devices (basic I/O, speed drives, ...). Both the event-triggered (asynchronous PDOs) and time-triggered (synchronous PDOs) approaches will be considered.

The final 2 weeks will focus on the hierarchical control architecture, as well as an example of an inter-connection technology commonly used between layers 2 and 3.

7 Scheduling

The course has been scheduled assuming a duration of 15 weeks.

Week	Type	Topic
1 – Introduction		
1	Lecture	Introduction to computer communications. OSI reference Model.
1	Seminar	Research of protocols, and location within the OSI reference model.
1	Laboratory	Analysis of protocols using protocol analyser (wireshark)
1	Miniproject	Presentation of project goals
2	Lecture	Foundations of industrial networks – an historical perspective.
2	Seminar	Research of field-buses (WorldFIP, MAP, Profibus, IPnet, ...)
2	Laboratory	Analysis of timing properties of control loops.
2	Miniproject	Requirements analysis, including timing requirements.
2 – Modbus/TCP		
3	Lecture	Modbus - Data model and Protocol Architecture.
3	Seminar	Structure of code implementing Modbus protocol
3	Laboratory	Implement a basic Modbus Client and Server Aplication
3	Miniproject	Desgin and structuring of control application
4	Lecture	Modbus TCP protocol
4	Seminar	TCP/IP and the Sockets API
4	Lab	Implement a basic Modbus/TCP Client and Server
4	Miniproject	Testing of modbus client and I/O address mapping
3 – Discrete Event Control		
5	Lecture	Discrete control logic
5	Seminar	Research discrete event systems modelling (grafcet, SFC, Petri Nets, ...)
5	Lab	Implementation of state machine based control logic
5	Miniproject	Implement basic control logic
6	Lecture	Synchronisation of control in discrete event systems
6	Seminar	Research synchronisation in distributed systems.
6	Lab	Implementation algorithms of state machine synchronisation
6	Miniproject	Implement complex control logic
4 – Modbus/RTU		
7	Lecture	Serial communication protocols - Modbus RTU and Modbus ASCII
7	Seminar	Structure of code implementing Modbus serial protocol
7	Lab	Implement a basic Modbus/RTU Master (on computer)
7	Miniproject	Add control logic that uses input obtained from Modbus/RTU master
8	Lecture	Overview of micro-controller programming
8	Seminar	Propose structure of code implementing Modbus serial protocol on micro-controller
8	Lab	Implement Modbus/RTU slave on micro-controller
8	Miniproject	Mapping of physical I/O to Modbus points and registers
5 – CAN		
9	Lecture	Introduction to the CAN protocol
9	Seminar	Research application areas of CAN networks (vehicular, avionics, industry,...)
9	Lab	Configuring the mcp2515 controller over SPI (on micro-controller)
9	Miniproject	Build a library of functions to access CAN controller
10	Lecture	Simple messaging using the CAN protocol
10	Seminar	Industrial communication solutions based on CAN
10	Lab	Configuring a CAN Network
10	Miniproject	Sending and receiving CAN messages.
6 – CAN Open		
11	Lecture	CAN-Open: The Object Dictionary (OD), and PDO transfers
11	Seminar	Research methods of implementing an OD
11	Lab	Implement a basic CAN-Open OD
11	Miniproject	Simple distributed control application based on sending and receiving asynchronous PDOs
12	Lecture	CAN-Open: Synchronous PDO transfers
12	Seminar	Research configuration of Synchronous PDOs in the OD
12	Lab	Implement periodic Synch message, and PDO response
12	Miniproject	Add synchronous data transfer to distributed application.
13	Lecture	Response time analysis of Event and Time triggered networks
13	Seminar	Research pros and cons of time triggered vs event triggered approaches
13	Laboratory	Calculate response times in specific sample scenarious.
13	Miniproject	Determine maximum response times of trafic in miniproject.
7 – Hierarchical Control		
14	Lecture	Industrial Communication Architectures (CIM, ISA88/95)
14	Seminar	Research on OPC, MAP, MMS, CIP, Profinet
14	Laboratory	Hierarchical control architectures
14	Miniproject	Add hierarchical supervisory control of distributed control application.
15	Lecture	Data transfer with OPC
15	Seminar	Research commercial OPC offerings
15	Laboratory	Access process data using an OPC/Modbus gateway
15	Miniproject	Presentation of the project(s)

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