EEE 3008: Industrial Automation & Robotics,

1. Section 1: Module Introduction, Overview and Roadmap.

1.1. Section 1 Aims.

After completing this section you should:

- Have a top-level appreciation of the main topics that will be covered in the Module.
- Understand the way in which the module will be delivered and examined.
- Have an appreciation of the impact that automation has upon manufacturing/production processes.
- Understand the three-level hierarchical model of an automated manufacturing system.

1.2. Introduction

1.2.1. The impact of automated systems upon modern manufacturing and production systems is profound and for the developed world, most facets of our lives are affected by the benefits of automated processes. Most products we use, food we eat, clothes we wear, vehicles that we move around in and even buildings we inhabit are the result at least in part of some automated manufacturing process.

1.2.2. This module will provide you with a structured approach to studying topics in the fields of Industrial Automation, Robotics and Artificial Intelligence. The size of the module dictates that we'll be selective in the topics that we cover, but we are going to discuss a very broad range of issues. The approach that we'll take is to talk about the theory of specific approaches or the problems posed by particular automation problems and then explore solutions and methods by means of examples and case studies.

1.2.3. Delivery of the module will be through formal lectures and informal seminars, and for the MSc students Self Directed Learning sessions. Each week we’ll have a two hour-long lecture session that will be split into two 50 minutes long lectures with a short break in between. The MSc students (EEE8005) will have a 1 hour SDL session each week located in the computer cluster in which we’ll explore some of the topics in more detail. The SDL sessions will largely consist of a short presentation and the provision of a worksheet for student completion. I’ll also hold seminars separately for the Undergraduates (EEE3008) on alternate weeks. The purpose of these undergraduate seminars is to allow you a forum to raise any issues or problems that you wish to discuss and to generally make sure that everyone is comfortable with the various topics covered in the formal lectures.

1.2.4. The Module examinations are at the end of Semester 1 in January. We’ll discuss the precise format of the examinations in a couple of revision lectures at the end of this term in December. The purpose of the examinations is to verify that you have understood and can apply various methods discussed in the lectures. As this year the module has been changed a little the content of the exam paper will vary somewhat from previous years, but you will only be examined on topics that have been covered in one of the lectures (or SDL sessions for MSc students).
1.3. **Module Roadmap**

1.3.1. The Module Roadmap showing the topics to be covered in each lecture is shown below:

<table>
<thead>
<tr>
<th>SESSION</th>
<th>DATE</th>
<th>TIME</th>
<th>LOCATION</th>
<th>TOPICS TO BE COVERED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lecture 1</td>
<td>29/01/2015</td>
<td>14:00-16:00</td>
<td>KGVLT1</td>
<td>Module Introduction, Overview &amp; Roadmap, Explanation of structure and topics</td>
</tr>
<tr>
<td></td>
<td>01/10/2014</td>
<td>17:00-18:00</td>
<td>COMP LAB</td>
<td>Briefing on Simulation Methods / MatLab/Simulink, Examples of Simple Plant Modelling</td>
</tr>
<tr>
<td>Lecture 2</td>
<td>06/10/2014</td>
<td>14:00-16:00</td>
<td>KGVLT1</td>
<td>The Device Level - An Overview of Sensors &amp; Actuators</td>
</tr>
<tr>
<td></td>
<td>08/10/2014</td>
<td>17:00-18:00</td>
<td>COMP LAB</td>
<td>Detailed discussion of various sensor and actuator types</td>
</tr>
<tr>
<td>Lecture 3</td>
<td>15/10/2014</td>
<td>14:00-16:00</td>
<td>KGVLT1</td>
<td>On-Off Control - Background to Relay-based Control Systems</td>
</tr>
<tr>
<td></td>
<td>20/10/2014</td>
<td>14:00-16:00</td>
<td>KGVLT1</td>
<td>Programmable Logic Controllers (PLCs) - Background, Programming Methods</td>
</tr>
<tr>
<td></td>
<td>22/10/2014</td>
<td>17:00-18:00</td>
<td>COMP LAB</td>
<td>On-Off Control Exercises - Relay Control System Exercises</td>
</tr>
<tr>
<td>Lecture 4</td>
<td>27/10/2014</td>
<td>14:00-16:00</td>
<td>KGVLT1</td>
<td>Modelling &amp; Control of Linear Systems: FPI/FD Controllers, Ziegler Nichols Tuning Examples based on Motor Control problems</td>
</tr>
<tr>
<td></td>
<td>29/10/2014</td>
<td>10:00-11:00</td>
<td>ST.FE.II.03</td>
<td>Practical Examples Q&amp;A; Review of any problems, DC Motor Control Exercise</td>
</tr>
<tr>
<td></td>
<td>29/10/2014</td>
<td>17:00-18:00</td>
<td>COMP LAB</td>
<td>DC Motor Control Experiment Exercises</td>
</tr>
<tr>
<td>Lecture 5</td>
<td>03/11/2014</td>
<td>14:00-16:00</td>
<td>KGVLT1</td>
<td>Fuzzy Sets and Fuzzy Control Systems</td>
</tr>
<tr>
<td></td>
<td>05/11/2014</td>
<td>17:00-18:00</td>
<td>COMP LAB</td>
<td>Use of Fuzzy Control applied to DC Motor Position or Speed Control</td>
</tr>
<tr>
<td>Lecture 6</td>
<td>10/11/2014</td>
<td>14:00-16:00</td>
<td>KGVLT1</td>
<td>Nonlinear Control - Simple Pendulum, Inverted Pendulum, Interconnected Tanks Mathematical derivations and control methods</td>
</tr>
<tr>
<td></td>
<td>12/11/2014</td>
<td>10:00-11:00</td>
<td>ST.FE.II.03</td>
<td>Q&amp;A; Review of any problems, Nonlinear control discussion</td>
</tr>
<tr>
<td></td>
<td>12/11/2014</td>
<td>17:00-18:00</td>
<td>COMP LAB</td>
<td>Review of answers to PLC homework / General Q&amp;A session / Mid-term feedback</td>
</tr>
<tr>
<td>Lecture 7</td>
<td>17/11/2014</td>
<td>14:00-16:00</td>
<td>KGVLT1</td>
<td>Introduction to Robotics, Inverse Kinematics &amp; Kinematic Designphans</td>
</tr>
<tr>
<td></td>
<td>19/11/2014</td>
<td>17:00-18:00</td>
<td>COMP LAB</td>
<td>Nonlinear Control Exercises - Modelling the Inverted Pendulum</td>
</tr>
<tr>
<td>Lecture 8</td>
<td>24/11/2014</td>
<td>14:00-16:00</td>
<td>KGVLT1</td>
<td>Robotics &amp; Kinematics, Forward, Inverse Kinematics, Inverse Kinematics, Denavit-Hartenberg Method</td>
</tr>
<tr>
<td></td>
<td>26/11/2014</td>
<td>10:00-11:00</td>
<td>ST.FE.II.03</td>
<td>Q&amp;A, Robotics Problems &amp; Examples</td>
</tr>
<tr>
<td></td>
<td>26/11/2014</td>
<td>17:00-18:00</td>
<td>COMP LAB</td>
<td>Discussion of Q&amp;A method, Further Examples</td>
</tr>
<tr>
<td>Lecture 9</td>
<td>01/12/2015</td>
<td>14:00-16:00</td>
<td>KGVLT1</td>
<td>Review of TDL, Examples, Robot Arm Orientation, Robot Velocity Kinematics Linear &amp; Rotational Components</td>
</tr>
<tr>
<td></td>
<td>03/12/2015</td>
<td>10:00-11:00</td>
<td>ST.FE.II.03</td>
<td>Q&amp;A, Revision session</td>
</tr>
<tr>
<td></td>
<td>03/12/2015</td>
<td>17:00-18:00</td>
<td>COMP LAB</td>
<td>Q&amp;A, Revision / Exam Discussion</td>
</tr>
<tr>
<td>Lecture 10</td>
<td>08/12/2015</td>
<td>14:00-16:00</td>
<td>KGVLT1</td>
<td>Revision Lecture</td>
</tr>
<tr>
<td></td>
<td>10/12/2015</td>
<td>10:00-11:00</td>
<td>ST.FE.II.03</td>
<td>Q&amp;A, Revision / Exam Discussion</td>
</tr>
<tr>
<td></td>
<td>10/12/2015</td>
<td>17:00-18:00</td>
<td>COMP LAB</td>
<td>Q&amp;A, Revision / Exam Discussion</td>
</tr>
</tbody>
</table>

**Fig 1.1: Module Roadmap (Subject to Change)**

1.3.2. The course thus splits into the following primary areas: an Introduction to Industrial Automation, a discussion of various control system components, Relay-based On-off Control, Programmable Logic Controllers (PLCs), Conventional (PID Type) Linear Control, Fuzzy Control Systems, an Introduction to Nonlinear Control Problems, Robotics and Robot Kinematics
1.4. **Industrial Automation – Background Discussion**

1.4.1. Since the introduction of computers into the manufacturing workplace, Information Technology (IT) and Automation Systems have revolutionised the way in which manufacturing industry operates. This applies to the general organisation and procedures adopted by manufacturing industry as well as specific methods and techniques of manufacture.

- Essentially Industrial Automation applications might be considered in 3 broad categories:
  - Replicating the actions of a human production engineer.
    - *E.g.* Robotic welders on an automobile production line. PCB population & production.
  - Facilitating Operations that a human manufacturing engineer couldn’t readily undertake because of size, speed, resolution or complexity of operations.
    - *E.g.* Large scale machining. Integrated circuit manufacturing. Real time high-speed process control requirements.
  - Undertaking production control in hazardous environments.

1.4.2. The introduction of automation has resulted in several benefits to industry:

- Decrease in processing times.
- Improved product quality arising from computer control; exactly repeatable production processes.
- Reductions in waste (less rework) and an associated reduction in costs.
- The replacement of human operators in hazardous environments.

1.4.3. There are also a whole range of other benefits that are less obvious but of great importance:

- Greater understanding of the manufacturing process, allowing easier identification of bottle-necks (critical operational constraints).
- Better production scheduling, making maximum use of the production facilities.
- Greater flexibility in response to changes in design, customer requirements and competition.
- Shorter ‘lead times’ in designing new products.
- Faster identification of faults in both product and processing machinery.
- Ability to identify deterioration in equipment before actual failure, reducing production ‘down time’.

1.4.4. In a system that must be flexible, its individual components and processing systems must also be flexible. They must be capable of changing their operational parameters, tooling or processing operations at short notice, perhaps on a job-to-job basis. This is where computer based automation is very effective.

1.4.5. Computer systems imply programmability and decision making capability, i.e. **intelligence**. Intelligent production systems, cells & work stations and even individual cell components are at the heart of the flexible capability of advanced manufacturing systems.

1.4.6. It is for these reasons that automation technology is considered an asset. Although as engineers it is the technology that interests us, for businesses it will be the advantages that the application of this technology can bring to production that is the driving force in bringing the technology to the work place.
1.5. **Manufacturing Organisation**

![Fig 1.2 Conventional Manufacturing Flow](image)

1.5.1. Consider a generic manufacturing operation as depicted in figure 1.2. Suppliers provide components and subassemblies that are held in the Parts Inventory. These are released to manufacturing through the Kitting process and, in this case, go onto 3 different production lines, each of which manufactures a product or a subassembly. These are then tested and either moved to Product Inventory or combined with output from other production lines to configure different products which are in turn tested and stocked in Product Inventory.

1.5.2. The control of the Manufacturing Process, triggering purchase orders to suppliers, initiating the release of components to manufacturing from Inventory and the overall coordination of activities to ensure that adequate Product Inventory is held to meet customer needs is the function of a central Planning & Scheduling organisation as shown in Fig 1.3.

![Fig 1.3 Planning/Scheduling Function in Conventional Manufacturing](image)
1.6. **Automated Manufacturing**

1.6.1. Since the mid 1950s we have witnessed the introduction of increased levels of automation into many manufacturing and production processes. Industrial robots, working in self contained Automation Cells, can handle, assemble and test components and products.

1.6.2. The introduction of automation and, in particular, fully automated manufacturing operations was accompanied by recognition of an increased need to coordinate activities. Initially this took the form of simple inventory management – ensuring that sufficient components were available for the production lines and that finished product inventory levels didn’t become excessive. Automated plant use conveyors, pallet movers or mobile robots to transport components / assemblies between automation cells and there is clearly a need to manage the flow of materials through the plant. Thus any Coordination function should also gather information from each of the production lines and individual automation cells in order to ensure that the overall flow of materials, part finished assemblies and products through the plant was efficient as possible. There is little point in having a fantastically efficient robot that can assemble a PCB in 2 minutes if it needs to wait for long periods whilst components and sub assemblies are provided for it.

1.6.3. This desire for efficiency and hence visibility, coupled with the availability of computational resources and automation components has completely revolutionized the way in which we manufacture many products.

1.7. **The Generic Automation System**

1.7.1. At its most general level an automated manufacturing process involves positioning, processing and moving. In order to be able to interact with raw materials the automated system needs to be able to recognize the position of itself and the materials. Any processing (e.g. welding, cutting, painting, machining, assembling etc.) requires accurate positioning of the materials and appropriate tools to ensure safe, reliable and repeatable operations. There is also a clear need to be able to determine that state of the operating system, e.g. to ensure correct pressures, temperatures etc. are being achieved. The implication is that our system needs to have sensors to measure status of various parameters and actuators to implement movement or tooling operations.

1.7.2. In fact the various elements of an automated process can be viewed as (and indeed are) elements of a control system. Fig 1.4 shows a generic diagram of an individual control loop of a part of an automation cell. You should note that this generic description applies equally well to process type activities (petrochemicals, pharmaceuticals, food processing, power generation). There is some target plant (e.g. position of a robot arm, speed of a cutting machine, liquid level in a tank), which has associated with it a profile of desired performance. There is a sensor that measures the actual plant performance and a controller that uses the error between actual & desired performance to control an actuator that affects the plant’s performance.

![Fig 1.4: Control System View of Component of Manufacturing/Production Activity](image-url)
1.7.3. In fact most Automated Manufacturing Systems include the following components:

- **Communications Networks** – used to transfer data & control signals.

- **Supervisory Control & Data Acquisition (SCADA) System** – coordinating overall line & capturing data.

- **Programmable Process Control Equipment** – lower level programmable control devices (e.g. PLCs).

- **Mechanical Components** – conveyor belts, automated guided vehicles etc.

- **Sensors** – to obtain measurements & data from the manufacturing system.

- **Actuators** – Valves, Motors, Hydraulic pistons (robotic arms) etc.

- **Tooling** – Cutters, Welding torch, spray head, component holders etc.

- **Manual Stations/Operator Panels/Terminals** – Provide visibility and supervisory control to human operators.

1.7.4. A typical automated production line consists of a transportation system and several Automated Manufacturing Cells. It is clear that there are requirements for different controllers within a single Automation Cell to communicate with each other and with a coordinating high level (or supervisory) system. The transportation system itself will have various sensors and actuators mounted on it to control and monitor material positions and to log product information. A typical flexible manufacturing cell consists of sensors, actuators, process controllers, manual stations, mechanical linkages and pneumatic components. All these elements must communicate with each other e.g. sensors and actuators will be connected to the process controller.

1.7.5. Between individual process controllers communications will be required to allow co-ordination of various activities within the Automation Cell; there are likely to be mechanical/logical interlocks and an alarm/emergency shutdown system to protect equipment and assure safe operation.
1.8. ISO Standard Three-Level Hierarchical Model of an Automated Manufacturing System

1.8.1. Communications in a factory environment consists of different networking levels. These range from the simplest network inside a machine, to the network running around the shop floor, the design room, the management and finance departments and ultimately to the corporate level, where worldwide communication may be involved. It is certain that this communication will involve the Internet. In fact the 21st century may see the advance of a factory completely remotely controlled over the Internet from one central site elsewhere in the world. (Covered in EEE8105/EEE8006: Distributed Control Systems)

1.8.2. An automated manufacturing system may be described as a three-level hierarchical model established by the International Standards Organisation. As shown in Figure 1.5, a hierarchy of communication systems is required to meet the needs of all the elements within a manufacturing environment. Higher-level networks are not suitable to implement the communication and control mechanisms required at the physical operations level. Similarly, lower level networks, such as CAN protocols, could not possibly be used to perform tasks that require a lot more than the simple interconnection of sensors and actuators in an automation cell.

![Fig 1.5 Three Level Hierarchical Model of Automation Networks](image-url)
1.9. **Just In Time (JIT) Manufacturing Principle**

1.9.1. The application of IT as a whole has allowed companies to make far better use of information relating to all aspects of manufacturing goods. Computers can store far greater quantities of data, whilst allowing faster access to requested items. Greater processing power allows in depth analysis of data collected, producing meaningful information that can be studied for future planning, and greater processing speed allows faster decision making about the current state of production on the shop floor.

1.9.2. A consequence of these changes has been the appearance of the 'Just In Time' (JIT) principle. The basic idea of JIT is that all necessary materials, components and instructions for processing arrive at the processing site just as it has completed its last operation. The impact on a company that adopts this principle can be very dramatic. Figure 1.4 shows JIT structure for our generic manufacturing operation.

![Figure 1.4 JIT Manufacturing](image)

1.9.3. The first observation is that instead of carrying inventories of components or finished products, the manufacturing operation is set up in such a way that the receipt of a customer order triggers a JIT order to a supplier who is primed to have components IMMEDIATELY available. These components and subassemblies are fed straight from Goods in Inspection through kitting to the production lines and as soon as tested products emerge they are shipped to the customers that placed the orders.

1.9.4. There are clear financial benefits of this sort of operation – the fact that the Company no longer needs to hold inventories of components or finished products means that its cash isn’t being used up paying for those materials. This is a massive benefit in terms of cash levels in the business. Also in markets where products rapidly evolve (e.g. modern electronic consumables) the lack of inventory reduces the exposure of the company to component and product obsolescence.

1.9.5. On Blackboard there are four papers on different aspects of JIT that you should read as background to the general topic, along with three brief case studies discussing the implementation of automation in different industries.