Factories of the Future

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Abstract

The technology used in Manufacturing is changing at a faster pace than at any time since steam power was first introduced into factories. However, the changes are not related to sources of power, but to the very techniques used to control the manufacturing process. If our students are to compete in a global employment market, they need to understand the manufacturing process and the technological changes that are sweeping through our factories. Nowhere are these changes more apparent than in the Aerospace Industry – advanced technological products like aircraft (manned and unmanned) require advanced techniques to produce and test.

This paper presents an overview of a project running in the School of Computing, Engineering and Physical Sciences (CEPS) at the University of Central Lancashire (UCLan). The project consists of a mini-production line showcasing the application of Advanced Digital Technologies to the Manufacturing process. One aspect of the project is the development of a course that will take students with fairly typical manufacturing skills and experience and turn them into 'prime movers' of the next Industrial Revolution.

Industrial Revolutions

Looking back over the development of manufacturing technologies, the 'great breakthrough' is generally recognised to be the Industrial Revolution. What we understand as the Industrial Revolution came about because of the development of new energy sources. Water power had been around for 2000 years[1], and had started the mass migration from the villages into the towns to work in the factories. By 1800 we had flying shuttles (1733), Spinning Jennies (1777), James Watt's super-efficient steam engine (1763), and Richard Tevithick's 'moving' steam engines[2]. Within a few years of turn of the 19th century, we had the 'power loom', which replaced so many workers that it brought about the rise of the 'Luddites'[3], who smashed the new machinery because of the effect it was having on workers' jobs.

Steam power and new technology caused the first Industrial Revolution. The Second Industrial Revolution[4] came about as a result of cheap Electrical power and the continued development of technology. The advantage of Electrical power was that it was available 'on demand' wherever it was needed, and transportation costs were minimal. By the start of the 20th Century, steam was starting to give way to Electricity[5] - one of the advantages of the new, clean, efficient power source was that it allowed even further reductions in labour requirements whilst increasing productivity.

The Third Industrial Revolution is going on around us right now; again, around the turn of another new century. This one is slightly less easy to define, because there is no single 'big idea' driving it. This one has been taking shape for some considerable time, and is much more about ideas and technology than power and energy. Woody Allen characterises this very well in one of his sketches when he tells us about his Father losing his job; *'My father was fired. He was 'technologically unemployed'. My father had worked for the same firm for twelve years. They fired him. They replaced him with a tiny gadget, this big, that does everything my father does, only it does it much better. The depressing thing is, my mother ran out and bought one'*[6].

The drivers behind the third industrial revolution may seem different to the earlier ones. Scarcity of resources like raw materials and energy are significant, as is the relentless progress of technology, which brings an expectation of 'newer, faster, better, cheaper'. The new technologies driving these changes include renewable energy[7] , IT, and the new 'commodity' - *data*[8].

Data is a relatively recent driver in the ongoing third Industrial Revolution. The diagram below summarises the familiar DIKW[9] triangle as it might be applied to manufacturing. The raw data coming from a manufacturing or test process may just be a string of 1's and 0's, but when put in context, it becomes meaningful data, like the amount of power required by a process.

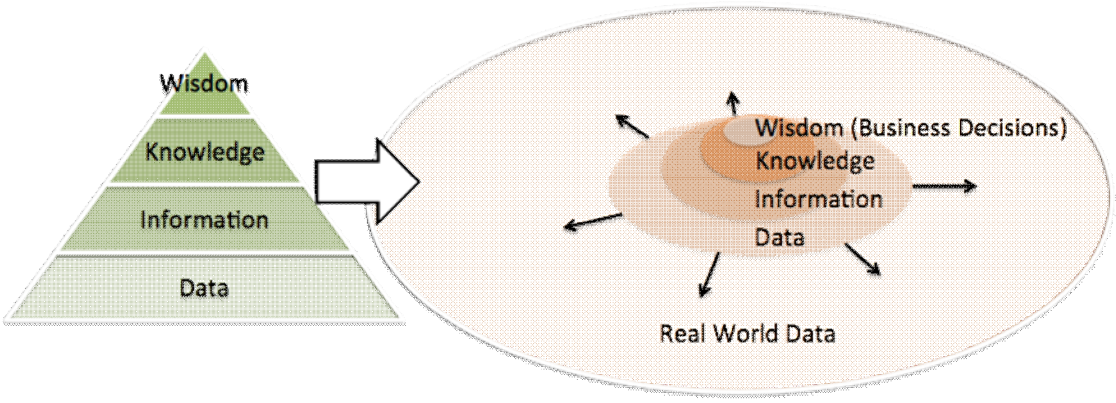

Figure 1: Data to Wisdom[10]

This can be translated into knowledge by systematic collection and interpretation of patterns and trends in data collection cycles. The final stage, turning knowledge into wisdom, comes about when we use our knowledge of the data to predict how certain modifications to a process will result in certain outcomes, like a more (or less) energy-efficient process, and a reduction in costs.

The application of the DIKW process to Energy usage is particularly significant for the UK, as our dependence on Energy imports continues to rise[11] . This is even more important when applied to the manufacturing process, since manufacturing remained the largest energy-consuming sector, accounting for 33% of total final energy consumption (TFC) in 2006.[12]

The DIKW concept has numerous applications to the manufacturing process, and the key to making use of it is the application of IT to make the transformation of Data into Wisdom. Statistical Process Control is one example of this, but our ability to capture and store large amounts of data, allied to the availability of cheap computing power to analyse the data, promises to become an increasingly important control mechanism in a manufacturing process.

In the West, however, and in Japan, there is now an unexpected additional constraint. One really significant resource that is set to become scarce is manpower itself. This time-bomb is already there in the demographics, as Rodney Brooks warns us in his video 'Remaking Manufacturing with Robotics'[13].

The 'Factory of the Future', then, is one which is energy/materials efficient, utilises advanced technology, and employs fewer workers. Looked at this way, it is perhaps not so different from those of the earlier Industrial Revolutions.

Based on the above concepts, we believe that Future Factories will need:

Energy efficient processes
Data measurement, storage and analysis
Automated assembly
Automated inspection and test of finished products
Computer-controller purchasing, storage and usage of raw materials and components

Efficient floor-planning and layout
Minimal human intervention
Remote configuration and operation (including remote 'presence'[14] , see figure 3)
The ability to work in 'lights out' mode

In order to support these facilities, there will need to be a strong data communications infrastructure that can facilitate the collection, processing and analysis of data, as well as provide secure external links allowing remote monitoring, control and configuration.

Robots, Data, Energy and Technology

The University of Central Lancashire is situated in the heart of the North West Aerospace industry, within a short distance of companies like BAe Systems and Rolls Royce. The North West has long been associated with manufacturing in the UK. The region:

- is the largest manufacturing region in the country. In particular, Lancashire has the largest concentration of aerospace manufacturing companies (over 800), and is the only major supplier of nuclear fuels in the UK
- has a manufacturing sector which contributes over £20 billion to the economy, of which £5 billion comes from Lancashire alone
- has manufacturing companies which employ 370,000 people in the NW, and over 100,000 in Lancashire
- has a lower proportion of SMEs and higher proportion of larger manufacturing industries than any other region
- has one of the few manufacturing sectors which remain buoyant, despite the prevailing economic conditions

The School has long-standing research links with the aerospace companies on its doorstep, and many of its students are drawn from (and eventually go to work in) the many advanced manufacturing companies which support the Aerospace Industry across the region. These links have led to the development of industrial support for expertise and research in Aerospace Non-Destructive Testing and Evaluation, Computer Vision, Robotics, Tribotechnology, Immersive and Interactive Visualisation, Medical Imaging, and the Effects of Radiation on Electronics. The latest interest within the Engineering area of the School is the concept of 'data to knowledge'[i], and its application to data flow within the manufacturing process.

All these concepts started to fit together when the School received Industrial Funding to set up an 'Advanced Digital Manufacturing Laboratory' (ADMT). This facility was to be a combination of the following:

1. A Research Centre, where the latest technology could be applied to the Manufacturing process.
2. A Knowledge Transfer 'showcase', where the School's expertise could be demonstrated to the local aerospace industry with a view to supporting the adoption of new technologies.
3. A Teaching Facility, where local Industry could send staff for up-skilling.

The initial concept was that of a 'mini' production line, where a workpiece could travel around a track, stopping off at various points allowing the application of new technologies to be demonstrated. The technologies were aimed at post-production measurement and test, the information gathered from the various stations being available to inform the manufacturing process. The picture in figure 2 shows the current phase of the development – the track passes around 6 configurable stations:

Figure 2: ADMT Facility

1. Warehousing system.
2. 2D Vision station
3. Laser camera for 3D profile scanning
4. Ultrasonic NDT scanning
5. Automated assembly
6. Screw tightening/fixing

The whole system is controlled by Programmable Logic Controllers which can communicate with each other and with the manual control interface. The stations are all networked together via a high speed fault-tolerant Industrial network provided by CISCO, which allows secure 'remote' operation and configuration. The facility is monitored over the web by steerable cameras suspended from the ceiling. The server rack in the corner of the facility manages remote control of the process plus data gathering and storage.

Each station is continuously monitored for Energy consumption via a system that provides instantaneous readings of power, voltage, current frequency and power factor. These 'smart meters' are networked together, and can be remotely accessed, allowing data to be gathered and processed either on-site or remotely.

The facility also aims to showcase the use of factory management systems, known as Manufacturing Execution Systems (MES). This kind of software manages the whole factory IT system, from orders, materials purchase and storage, to production scheduling, costing and delivery.

The remote operation facilities are intended to allow 'telepresence', whereby the factory can be run remotely whilst allowing a measure of direct access via remote presence. This remote presence takes a number of forms; all the instrumentation is available over the web, and cameras record moving images of the facility, allowing the results of remote control to be viewed.

'Telepresence' is not new – you can now buy your own personal avatar telepresence robot[14] which can move within an office environment and interact with colleagues whilst you remain at home. The ADMT group is working on the equivalent factory telepresent worker, which can directly interact in the manufacturing process, allowing minor maintenance tasks to be done remotely. It will move workpieces to and from storage, and act as the factory floor cleaner. It will provide 'on-demand' instrumentation where there is concern about the well-being of a particular process, or maybe just a shot of oil for a dry, squeaky bearing.

The facility is an up to date showcase, demonstrating a whole range of advanced 'digital' technologies, and the way that they can be used to enhance the manufacturing process.

Figure 3: Anybot Telepresent Robot[15]

Teaching and Research

Local industry was not long in learning about this facility - it has generated a huge amount of interest, and we regularly host visitors from both small and large companies who are interested to see these new technologies in action, and learn from us how they might be applied to their operation. The potential for links with local industry was one of the main drivers behind setting up the facility.

The Teaching and Research aspects have also been gathering momentum. Throughout the year we have been bringing engineering students over from our main campus to see the facility and learn about the technologies. Project work this year includes:

- Mobile Robot Collision Avoidance using sonar
- Remote operation via wireless networks
- Autonomous Robot operation
- Energy monitoring and data analysis
- Object recognition using image processing
- Robot Navigation using 'signposts'
- Automated assembly system using LabView
- Component identification and location using vision
- Automated ultrasonic NDT using a Robot arm
- RFID tagging and data collection
- Data gathering using .NET Remoting
- Web-based factory control
- Component recognition from CAD data

It has been interesting to note that the marks for the projects have been consistently above the 'norm' for the 120 students in our final year. It may be that good students 'self-select' for this type of project (rather too practical for the faint of heart), or it may be that the sheer interest and enthusiasm that this work engenders is producing above-average engagement from the students. This work ticks many of the employability boxes – a student hoping to enter the advanced manufacturing industry who can talk about any of the above projects at their job interview would be well ahead of many of their rivals.

The work at the ADMT facility has 'fed back' into the curriculum being delivered at our main site. Robotics, Image Processing and Software Development have suddenly become very popular. We can use the facility to provide examples of real problems that are faced in industry, whilst dealing with them in the context of an academic course. The kinematics involved in moving a screwdriver to engage with a screw (which we have previously located using image processing), and the consequences of being one millimetre out, suddenly take on a whole new relevance once a student has seen it go wrong! Students start to understand that even being 90% 'right' in the real world is nowhere near good enough.

Figure 4: Developing Robot control software

The project work grew out of necessity – there were so many things that needed to be done, and there are still lots of things that need to be done. The projects were done by students following 'standard' disciplines in Engineering, and provided an extra dimension for what were otherwise fairly traditional academic courses.

Curriculum Design

The design of a formal curriculum to deliver these skills was less straightforward. One of the main considerations revolved around the question *'What type of student needs to understand these technologies as they are applied to advanced manufacturing?'*. Electrical/Electronics students are fine until things start to move, and Mechanical students are fine until they need to gather data and write software. Computing students are good at databases, but can't design sensor and control systems. PLCs used to be firmly located in the domain of 'Technician' level courses; now PLC systems need to be adaptive, enable data collection, and communicate with each other using high-speed fault-tolerant networks. It became clear that the 'mix' of skills needed to develop and apply these new technologies in advanced manufacturing scenarios crosses the traditional academic boundaries (of both level and content). We looked at the technology in the facility, and started to ask ourselves what students would need to know to enable them to start applying these new ideas. We even struggled for a name for the discipline – it started out as 'Advanced Manufacturing', but we quickly realised that this was about the application of technologies, rather than the manufacturing process itself. We finally settled on 'Advanced Digital Engineering' as a title – it is still up for discussion.

We reconsidered the background and experience of the type of students who would be interested in this type of course. One thing we knew about full-time students is that they don't know much about industry, which was to be expected. The Advanced Digital Engineering course is a solution to a problem that full time students probably could not appreciate. Added to that is the fact that the limited experience of full-time students is not an appropriate foundation to build these new ideas onto. It seemed to us that part-time students who already have a manufacturing background would be most suited to this type of course, and would benefit most from it. This also held the potential to enhance links with their employers, who might see us both as a source of training for their employees, and as a source of experience about modern technologies. It was decided that the course should concentrate on part-time, employed engineering students.

Our University has long since had very strong links with 'partner' FE Colleges in the North West. We have validated a significant number of Engineering/Technology 'HE in FE' courses like Higher Nationals and Foundation Degrees. The Burnley Campus where the ADMT facility is located is shared between UCLan and Burnley College, and as such gives us access to a ready-made stream of part-time employed Engineering students who hitherto had no local progression route once they had completed their College courses. The students are already employed in the Manufacturing Industries of East Lancashire, and are exactly the students (and employers) we wanted to target with our new provision. Given that we already controlled the content of the Higher National and Foundation Degree courses, it became a simple matter of matching the existing traditional 'Engineering' curriculum with new material aimed at the advanced manufacturing technologies that the ADMT facility showcased.

The progression routes we identified are as shown below, indicating pathways for National, Higher National and Computer Aided Engineering (CAE) Foundation Degree students onto a final year 'top-up' degree in Advanced Digital Engineering:

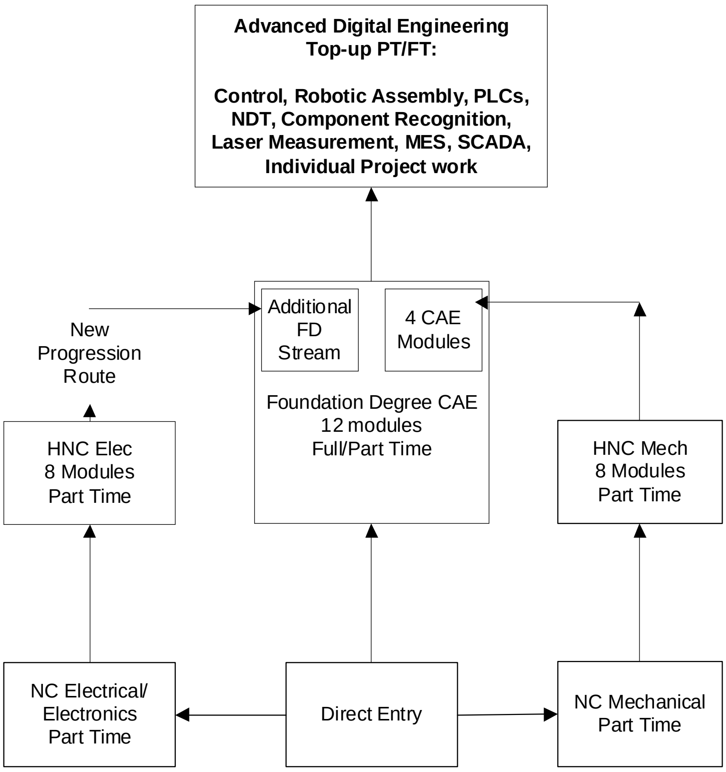

Figure 5: Progression Routes

The aim of the top-up course is to take students from varied backgrounds within an overall Engineering context and equip them to play a key role in the adoption of advanced digital technologies into a manufacturing context.

The modules we developed have neither an Electronic nor a Mechanical bias – it was an important original design goal to ensure seamless progression onto the course for more traditionally-focussed Electrical or Mechanical students. The modules all provide the opportunity to introduce the use of software as a data-processing tool and as a controlling mechanism. The staff who deliver the modules all have an interest in software and programming.

The final list of modules is as follows; they have been organised into two years of part-time study:

Year One

Instrumentation and Control	Design of systems that use a range of industrial sensors and actuators to implement control systems
Robotics and Mechatronics	Application of Robots to Manufacture, with the emphasis on intelligent robot systems and flexible assembly processes
Advanced Digital Manufacturing	A range of practically based case-studies including: • Intelligent process control • Non-destructive ultrasonic testing • Component recognition and tracking • Video/Laser scanning and measurement • Fault recognition and resolution • PLC programming on high-speed industrial networks • Data Collection and Analysis

Year Two

Manufacturing Software Systems	The operation of modern software-based Manufacturing Execution Systems, covering: • Data acquisition and interfacing. • Energy management (control, logging and projection). • Traceability of materials, components and finished products – batch numbers. • Materials sourcing, stocking and billing. • Quality systems. • Statistical process control. • Configuration management of drawing, designs, etc.
Double Project	Work carried out by the student in industry, although it may include lab-based work building up the case for introduction of new technologies into the manufacturing process. Project Management will be a key component of their work. Support in the form of regular one-to-one meetings with the project supervisor plus industrial visits. Progress presentations will be given by the students to their peers

A part-time top-up degree course does not give a lot of scope for changing perspectives, but that is one of the aims of this programme. Giving students new perspectives is an indirect way of influencing what happens back at their place of work, and that then provides us with a real opportunity to encourage the adoption of these new technologies.

The new technologies plus the explosion in data are the drivers of the latest Industrial Revolution. Our students will leave the course equipped with the ability to make judgements on how best to apply these new technologies in an advanced manufacturing context. We will measure the success of our course by the number of employers that subsequently make enquiries about more focussed training and development for their staff, and by the amount of consultancy work that comes our way. In that way, the facility will become a self-sustaining, developing resource for teaching, research, and the revitalisation of the North West Manufacturing Industries.

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