AC 2012-4777: ROBOTIC CELL USAGE IN INDUSTRY: THE REBIRTH OF A FRONTIER FOR MANUFACTURING ENGINEERING EDUCATION

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Robotic Cell usage in Industry: The Rebirth of a Frontier for Manufacturing Engineering Education

Abstract

The American manufacturing workforce is currently not well-trained to undertake increased modern day usage of robotics in the workplace [1]. In the past robots and computers were primarily used to aid in routine and dangerous tasks. The skill level necessary for operators, on these systems, were very specialized in nature, as different manufacturers had differing coding and operating schemes. The robotic systems employed were generally inflexible to changes in the product itself, product demand or even working on a queue of products in the same family. In the past decade there has been a major push in the field of robotic design for integrated robotic systems that work in tandem with human operators, making them more flexible and also imbuing them with an innate ability to produce multiple products in small lots and in a just-in-time manner. This added ability allows robots, that in the past worked independently, to communicate with other robots in flexible robotic cells and with human supervisors, sharing information, such as cycle time, work-in-progress, and problems associated with the undertaking of a routine. As more manufacturing firms continue to adopt operational improvement strategies like lean or agile manufacturing the focus will now shift to the integration of robots into the manufacturing system. Our current Manufacturing Engineering Education programs, nationwide, need to be aware of this impending change and how to embark upon introducing these concepts into the curriculum. This paper sets forth a framework for which systems engineering and robotics can coexist in our current pedagogical environments. The framework is based on the modification of the Manufacturing Engineering Program at Indiana State University. By utilizing, an interview session with one of North America's largest producer of oriented polypropylene films, the framework established seeks to find common ground for all manufacturing engineering programs nationwide.

Keywords: Robotic Systems, Manufacturing Engineering, Systems-based-Curriculum development, Curriculum Enrichment.

Robotics in manufacturing

Our economy is driven by a need to innovate, reliable and cost efficient solutions, and it is at this point in time in our history that there is a shift in the gravity of the role of engineering educators and researchers. The need for the rapid development of products, as well as, the need for their production in an efficient manner is paramount in an environment in which globalization will be a mainstay. Within the last decade there have been a significant amount of advances that have been made in the field of robotics technology and also in the area of Discrete Event Systems (DES). Robotics Technology advances have enabled improved operations in fields as diverse as manufacturing, logistics, medicine, healthcare and other commercial market sectors [1]. Robotics in manufacturing in recent time has led to the limiting of the human role in these operations to that of remote high level supervision. An enhanced understanding of the behavioral properties of resources in manufacturing systems has, also, led to solid theoretical premises for the analysis and control of the deployment of robotics in the sector [2].

Robotics, according to the Robotics and Automation Society of the Institute of Electronics and Electrical Engineers, relates to integrated systems that operate autonomously or semi-autonomously in cooperation with humans. Research centered on robotic systems focuses on the enabling of intelligent features to aid coping or adapting in unstructured environments. Automation, on the other hand, relates to computer integrated machinery, working in structured environments, autonomously, whose performance is appraised based on efficiency, productivity, quality, and reliability. Automated machinery are generally standalone pieces of equipment that are highly dependent on human supervision in the prevention of extended downtimes and the prepping of raw materials necessary for operation. Humans in these systems tend to possess less technical skills than their counterparts in robotic systems, who often work in tandem with their machinery[1,3,4].

While many have argued that the notion of robotics and manufacturing have been around for the last half century or more, what they have failed to realize is the intricate web that is being formed between research in the DES area specifically on resource allocation and its direct impact on the efficiency of manufacturing systems. This paper hopes to enlighten educators in this field about the growing need for graduates, from manufacturing engineering programs nationwide, as to the changing demands of employers in the field. Our expectations in this field should be that our graduates will find fewer and fewer job opportunities for themselves, however, the jobs they do find will require them to be able to abstractly think about manufacturing systems from a critical perspective. By noting the developments in the field of manufacturing, in the state of Indiana, and conducting an interview with a perennial employer in the state, it is hoped that a framework for the application of theories from the area of DES can be integrated in Computer Integrated Manufacturing (CIM) curriculums nationwide. According to the 2011 skills gap report done by Deloitte and the Manufacturing Institute, “the changing nature of manufacturing work is making it harder for talent to keep up.”

Indiana’s Manufacturing Story

Indiana ranks second, as the state most dependent on manufacturing for tax revenue, only Oregon is more reliant. Manufacturing is the state’s largest tax revenue provider; approximately

28% of all state tax revenue is derived from the sector [5]. In 1973 the state's manufacturing workforce peaked at 758,200, declining by an approximate 25% (572,900 jobs) three decades later [6]. The disappearance of 25% of the state's manufacturing workforce has not meant that there has been a similar decline in its' manufacturing output[7]. According to Jeserich et.al. (2005) and Dwyer (2011), traditional assembly-line jobs, in the state, have been replaced by high-skilled, high-tech, high-paying jobs. The 2010 New Economy Index released by the Kauffman Foundation of Entrepreneurship and The Information Technology & Innovation Foundation, ranked Indiana ninth among states in "manufacturing value-add", a term used to explain the difference in value between inputs into the production process and the value of final products sold. This confirms that manufacturers in the state are increasing their focus on high-value and high-tech products, such as, electric vehicles, jet engines, advanced electronics, lifesaving medicines, and medical devices [8,9].

An integral part of Indiana's continued prominence in these fields will have to be derived from its postsecondary education system. In particular vocational technology programs at both four and two year intuitions now have to revise their curriculums, and labs to meet the needs of the manufacturing community where 98% employ less than 500 workers per facility[5]. A heavier reliance on a highly skilled and flexible workforce is now the new norm. The Advanced Manufacturing Management (AMM) program, at Indiana State University (ISU), educates people who are sought by these modern manufacturing entities in the state. Graduates of ISU's AMM program are capable of working in a manufacturing facility that requires multi-faceted skills and a wide range of expertise, drawn mainly from the fields of Electronics, Mechanical, Control, Systems, Computer, and Software Engineering. However, lacking in this field is a broaching of topics specific to the area of Discrete Event Systems, which in recent times have enhanced our understanding of flexible robotic production systems.

The Roots of operational efficiency

Monies tied up in investments such as raw material, wages and overhead set a maximum limit to the quantity of products that can be profitably made during a single production run [10]. Setup costs are the sole determiner of the minimum amount of products that can be made in a single production run[10,11]. The problem of setup costs has dominated the focus of modern manufacturing systems for the past 80years. It was not until the Toyota Motor Company, developed and perfected their production system that the idea of setup costs was focused on as a potential productivity booster and profit generator. In the field of Industrial engineering the problem was studied mainly from the perspective of theoretical models in which simulations were done to optimize system usage based on Resource Allocation Models. Implementation of these solutions, provided by these models, in the field oftentimes negated intervening and moderating variables such as worker motivation, reorganization costs and production planning time. Often-time these variables failed to be addressed in theoretical models lending credence to the inappropriateness of system-wide adoption of operational improvement strategies in the area of robotic-manufacture. It took approximately 30 years for the entire manufacturing industry to fully understand how to implement operational improvement strategies, such as, Lean in their workplaces, and this process still continues today[12].

On average the US has seen a 2% increase in productivity annually since 1980, and has seen its manufacturing output grow by 2.5 times since 1970, even though employment in the field fell by 30% over that time period [13]. As we move forward achieving this rate of productivity is going to face an uphill struggle. One of the key ingredients of manufacturing's continued resilience is its' human capital. For the past three decades significant changes have happened to the basic job functions of a typical manufacturing worker. In general, modern manufacturing workers have been entrusted with greater autonomy carrying out their jobs through increased control of job functions, problem solving, communication, and team-based improvement initiatives [14]. The next phase of job change is on the horizon and it will require the incorporation of robotic operating knowhow into the very fabric of work itself. Two main reasons exist for this namely: 1) the continual incorporation of robotic systems in the undertaking of routine and potential hazardous tasks, and 2) the trend of smaller product lot sizes coupled with increased variety in products[3]. The ability of modern production systems to deal with the manufacture of multiple products in the same system has mainly been due to the focus on setup time reduction. In solely automated and robotic environments the skills needed for increased productivity are extensively technically based as hierarchical level programming becomes a main stay in flexible robotic cells.

Methodology for Developing the Educational Frame Work

In an effort to develop an educational framework an interview investigation will be conducted with input from a perennial employer who is a member of the Indiana State University's Advanced Manufacturing Management program advisory board. The investigation will span seven stages, namely:

1. Thematizing
2. Designing
3. Interviewing
4. Transcribing
5. Analyzing
6. Verifying
7. Reporting

Thematizing refers to why this research needs to be undertaken. In this case it refers to an expanding of the CIM curriculum to include the adoption of DES theories and other external influences to robotics course work. It is postulated that small to medium size manufacturing facilities will have a defined need for prepared skilled talent that graduate from Manufacturing Engineering programs nationwide, in order to be able to work in advanced manufacturing environments. These environments are typified by their use of flexible machinery in small production cells that require only remote human monitoring. Thematizing also refers to what the investigation will be focused on and in this instance it refers to small to medium size manufacturers in the state of Indiana who have small and flexible operations that demand the use of flexible robotic systems.

A flexible robotic cell is one that consists of a number of automated production machinery that are modular in nature, with finite buffering and processing capacity. The machinery located in the cell are interconnected via an automated material handling system which is made up of a transporter or transporters handling one work-piece at a time. For instances where modular production machinery are located in close proximity to each other, robotic manipulators, such as robotic arms, are employed as the automated material handling system. On the other hand, cells that have spatially dispersed automated production machinery employ automated guided vehicles or overhead monorail systems. The modularity of the automated machinery cell allows it to support the simultaneous production of more than one part at each workstation. The parts being worked on at each workstation could possibly be different products with distinct processing sequences.

The design of the research will be based on the road map provided by the Computing Community Consortium (CCC) and the Computing Research Association (CRA). Interviewing participants will be done in a manner that will seek to gauge their use and need for the critical capabilities cited by the CCC and CRA. The road map describes the vision for the deployment of the following critical capabilities:

1. The use of robotics in manufacturing environments that have built in capabilities that allow their operation in unstructured environment,
2. Robots that are imbued with human-like dexterous manipulation,
3. Robotic systems that are adaptable and can undergo changes to their assembly sequences,
4. Robots that work in tandem with human operators,
5. Robotic systems that are Autonomous,
6. Robotic systems that allow for the rapid deployment of assembly lines,
7. Green manufacturing in robotic systems,
8. Model based integration into robotic manufacturing systems from design through to supply chain,
9. Interoperability of component robotic technologies,
10. Robotic technologies in the Nano manufacturing arena.

In order to assess the needs of Manufacturing Engineering a review of the technical and managerial competencies currently provided to our students needs to be sought. In addition an evaluation needs to be made of how important robotic systems will be to manufacturers in the future and how they perceive this will affect graduates from manufacturing engineering programs nationwide. Five main areas are therefore chosen in an effort to gain a better understanding of the change in technical and supervisory needs many manufacturers may face or are currently facing. These are: 1) knowledge of the supervisory tools necessary to support and maintain manufacturing processes, 2) Active acclimatization to the role and use of computing systems in industry, 3) A foundational knowledge and practice of the standard electrical principles utilized in industrial operations, 4) A foundational knowledge and practice of the standard mechanical principles utilized in industrial operations, and 5) Cross-integration of the four fields undergirding modern manufacturing.

The interview was conducted with the aid of a tape recorder that aided the transcribing process. Questions were asked one at a time and the interviewer tried to be neutral to prevent biased responses. The transcribing and analysis steps are presented in the results and discussion section of this paper. A diagram depicting the main themes identified by the interviewee throughout the interview is presented in the discussions section. It also provided direct responses to discontinuities seen in the CCC's and CRA's road map and helped to better our understanding of industry trends. The interview answers are presented in the results section of the paper.

In an effort to focus data collection on a specific detailed account of Flexible Robotic Cell integration into a manufacturing operation, a company located in the southwestern Indiana area was sought. The company employs 620 workers nationwide and approximately 530 at its' large manufacturing site in southwestern Indiana. The company is classified as being small utilizing the delineation of the U.S. Small Business Administration (SBA)[15]. Contrary to its' small size attribute, the company is one of the largest producer of oriented polypropylene films in North America. Their products are utilized in several packaging and labeling applications, however, notwithstanding this advantage they were forced to declare bankruptcy in 2004. The interview conducted centered on the extent of robotic machinery use and also on the technical expertise that was required by employees. At the heart of our interview questions was a determination of whether or not setup time, cycle time and inspection time reduction were a focus of the entity. It was thought that asking questions as it related to these factors would explain whether or not more automated machinery versus robots would be purchased. Also, it was expected that the deployment of employees on the factory floor would be highly skilled and knowledgeable about the operations being performed by the machinery.

Five main questions were asked as it pertained to robotic versus automated systems. The questions are provided below:

1. Does your facility use Flexible Manufacturing System technology where two or more machines are controlled by computers?
    a. Are these computer controlled machines automated, therefore, do they require constant human attention?

2. Is the current goal of your production system to increase product customization or product volume?
    a. Has there been any new equipment purchase to support any of these goals?
    b. Have these new equipment purchases reduced the amount of machinery necessary to make that product?

3. Has your company in recent time made any new equipment purchases?
    a. Has the acquisition of new machinery affected the need for more skilled workers?

4. Is a future goal of your company to obtain more highly skilled workers that can run new robotic machinery?

5. Are you using planning models to help you schedule production operations?

Results

The results obtained from interviewing the company's liaison reflected the changing demands on employees at their facilities. A reorientation of manufacturing operations towards more robotic systems resulted in a marked improvement in the company's bottom line allowing them to exit from bankruptcy in 2005. In an effort to obtain a response from the interviewee about the use of robotic systems in the facility the first question was posed. The response elicited from the question clarified that the machinery being used in the facility were actually robotic in nature. For example, workers at the facility engage in remote level supervision for most of the high-volume production operations. The facility employed dedicated automated machinery which was remotely monitored by technicians that were trained extensively on the machine's key features. When asked if those machines had replaced older ones in the past, the respondent recanted a common theme throughout all of their operations in which when a higher quality CNC machine was introduced into production it customarily replaced two or more older models. The machinery they are currently utilizing are in operation 24/7 over a daily three shift time frame and can be left unattended for several days. Of particular benefit to the operations is that they are able to divert employees from direct equipment supervision to other tasks.

On the issue of product volume and customization, the company engaged in both as they had few large volume customers and multiple small volume customers. Due to the mixed customer base the employer required that robotic machinery utilized be able to modify their operation based on product desired by their customers and the demand. Robotic cells were therefore used to make a family of products for multiple customers. With every new equipment purchase the company has also sought to reduce the amount of machines necessary to do a job. With that goal in mind less space is required on the shop floor and new products can be introduced at a much faster pace than previously. Of particular importance to the purchase of new equipment is the training of a workforce that is able to customize products on computer systems tied to the robotic machinery. Flexibility in worker skills is something that is sought by the company and it comes from two separate areas. One is worker experience, which is thought to be a good gauge of time and project management skills and the other is training on similar type of equipment or systems. The concept of multiple automated equipment integration is vital to the company, as each newly acquired equipment purchase requires these skilled employees with intimate knowledge of the company's intranet system.

The final question asked pertained to the formulation of production schedules and how models were used to aid in these decisions. With the availability of instantaneous data production scheduling becomes more flexible as downtimes can be predicted in advance and products can be shifted from one production cell to the next, if necessary. No formal models were used to obtain predictions for future scheduling events as historical datasets were sufficient to base machinery utilization. However, most noteworthy was the fact that the way this facility coped with a shortage of skilled labor was by the implementation of more robotic and computer integrated systems. Current employees at the facility are therefore forced to adapt as there is an increased need for problem solving skills. Due to the ease of worker adaptability, the implementation of new robotic technologies offsets their need for an increased workforce.

Discussion

The overarching goal of this paper was to use insight garnered from literature and a chosen participant to highlight a need for a refocusing of Manufacturing Education Programs nationwide. In an effort to become more productive manufacturers are now being forced to adopt the latest technologies which come with increasing capabilities, such as, model based integration and design, rapid deployment of assembly lines, and robots working in tandem with humans. While these capabilities are not something we are explicitly integrating into our curriculums they will become more and more common place in the coming years due to factors such as an aging manufacturing workforce and the need for increased productivity. Most if not all four year Manufacturing Education programs have the basic underpinnings of Computer Integrated Manufacturing (CIM) in their curriculums[16]. However, they too are noticing these trends, such as the development of new concentrations in robotics. According to the 2011 Trends in Manufacturing Education Programs report, the fastest growing field in manufacturing is systems integration. Robotics provides Manufacturing Education programs direct access to the development of robust curriculums that are adaptable to changes external to the programs.

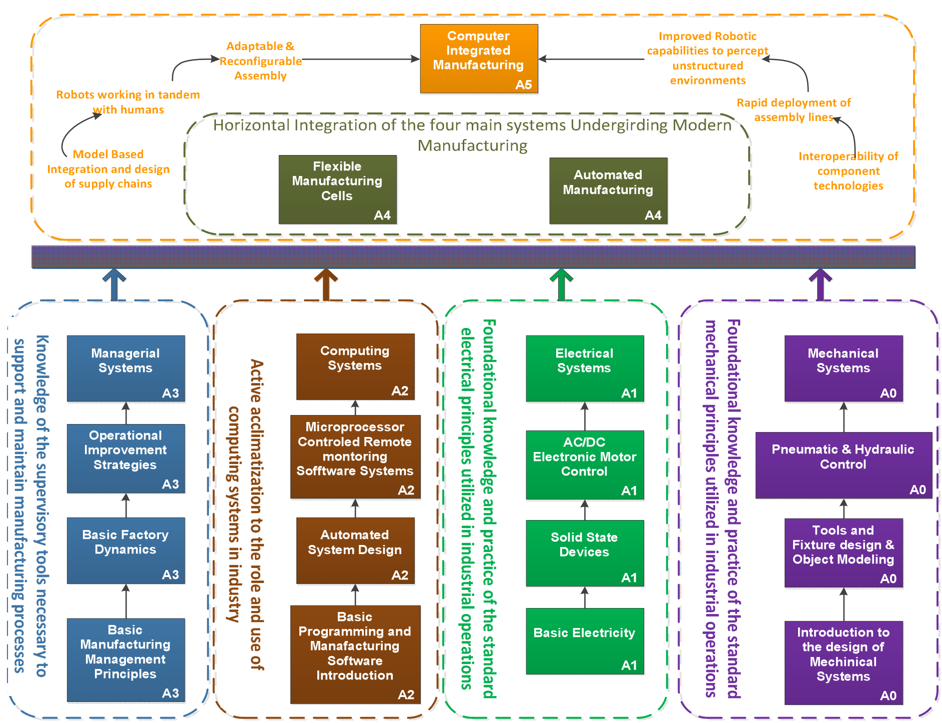

Figure 1: Basic Underpinnings of Computer Integrated Manufacturing and Future Technological Influences

The main objective of this paper is not to discount the fact that Manufacturing Education programs nationwide are lacking the basic utilities to equip their graduates. The opposite is actually true. As can be seen from figure1 undergirding these programs is their systematic equipping of graduates in four main areas, namely: 1) Managerial systems, 2) Computing systems, 3) Electrical systems and 4) Mechanical systems. Students pursuing a Manufacturing Engineering type degree are exposed to these areas from an expert point of view which imbues them with the necessary traits to horizontally integrate these skills in flexible and automated manufacturing cells. A true display of these higher level skills is what we would term in this field as being Computer Integrated Manufacturing (CIM). However, our understanding of CIM is now being challenged from external influences. These external influences can be seen at the top of figure1 and are namely:

1. Model based integration and design of supply chains,
2. Robots working in tandem with humans,
3. Adaptable and reconfigurable assembly
4. Robotic ability to percept unstructured environments
5. Rapid deployment of assembly lines
6. Interoperability of component technologies.

At the core of the CCC's and CRA's road map, produced in 2009, are the external influences which are goals that would be realized in a five to fifteen year period of time[1]. We are slowly reaching that time frame and what is very apparent from the interview conducted is that some of these influences are already being adopted by manufacturers nationwide. Rapid deployment of assembly lines and adaptable and reconfigurable assembly, through the use of robotic cells was a very apparent feature of the company studied. This capability is something that is becoming a more pronounced feature of modern manufacturing. When polled in the 2011 Manufacturing Education Programs report, educators stated that they have many courses that directly apply to manufacturing but they expressed that there still is a dire need for more electives in their curriculums. Ranking technical electives in terms of importance among Manufacturing Education programs nationwide one finds courses directly related to robotic systems such as Integrated System Design, Mechatronics and Computer Networking as being paramount to their programs survival[16]. It is not a surprise that these courses are being focused on by educators, because there is a strong demand, externally, for these skills in graduates.

If one looks at the four pillars of Manufacturing Engineering, seen in figure 2, what one can conclude is that there is definitely a focus on Automated Systems and Control in Manufacturing Education programs, however, nowhere is there is explicit reference to robotic systems. Robotic systems, as we defined in the introductory sections of this paper, refer to integrated systems that operate autonomously or semi-autonomously in cooperation with humans. Robotic system design focuses on the imbuing of intelligent features that allow for the adaption to unstructured environments, or sudden changes in product requirements. We therefore should expect our education programs to adapt to the widespread use of high-fidelity sensors, novel mechanisms and actuators, to promote cognition, robust perception and human robot interaction.

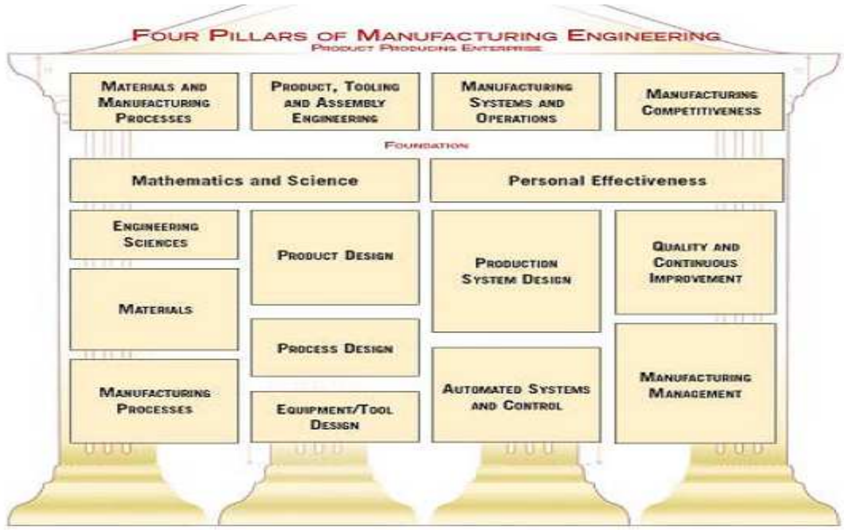

Figure 2: The Four Pillars of Manufacturing Engineering represented as a structure (Taken from: The National Center for Manufacturing Education)

Conclusion

As more manufacturing companies recover from the "Great Recession", they face the impending threats of an irreplaceable, ageing workforce and increasing global competition. The need for productivity improvement initiatives and technologies, therefore, is paramount[16]. At the forefront of this race is the adoption of the latest robotic technology that has the power to reduce, direct human supervision needs, the amount of machinery necessary for a given production process and the amount of time necessary for production runs, setup and inspection. Simply introducing students to an Automated System and Control based curriculum is not sufficient, as new thought needs to be given to the other impending external changes that are slated to appear within the next decade. To prepare to incorporate these changes into our curriculums, our professional, as well as, accrediting bodies need to lead the way. Individually, Manufacturing Education programs nationwide will have to form stronger bonds with their industry partners in which both instructors and administrators can gather empirical evidence to update their curriculums and laboratory infrastructure. The changes afoot are not specific to any one manufacturing sector. These changes are widespread and that is why we need to take note and modify our curriculums, expertise and student expectations accordingly.

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