Integrated manufacturing technology laboratory

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Abstract
The integrated manufacturing technology (IMT) laboratory is a future factory facility currently being built in the department of Industrial Engineering and Management (IEM) at the Ben-Gurion University of the Negev. The main goal of the IMT laboratory is to facilitate teaching and research on the integration of future factory concepts, cutting edge technologies of shop floor automation, and organizational information systems. This will be achieved through the integration of main IEM disciplines, such as intelligent automation, production planning, information systems, and human factors. The laboratory will be constructed to produce physical products, and the main production process will be an assembly process. Digital factory methods will be employed in shop floor control. Human factor methodologies will be employed for designing station controller interfaces and the monitoring screens of the laboratory control center. Green manufacturing concepts and product sustainability considerations will also be demonstrated. The objective of this paper is to describe the key challenges and the main implications for education and research of designing and building such a state-of-the-art integrated manufacturing laboratory.

Keywords:
Laboratory, Education, Digital factory, Computer integrated manufacturing.

1 INTRODUCTION

The first wave of integration of information technology (IT) into factories took place in the 1980s and was termed computer integrated manufacturing (CIM). The hope was for a fully automated and integrated computer control plant. Yet, system complexity and technological immaturity have raised obstacles to CIM implementation. Today, fundamental transformations are emerging in production management and organization [1, 2, 3]. Work at all levels is being re-shaped by e-work. Product life cycle management (PLM) is gaining importance and becoming the “forth leg” of enterprise information systems alongside enterprise resource planning (ERP), supply chain management (SCM), and customer relationship management (CRM) [4]. The digital future factory is becoming a reality for which future engineers must be prepared.

Hands-on experience was considered of tremendous value in teaching CIM [5], and several CIM systems suitable for higher education were developed [6-9]. Teaching the fundamental CIM concepts was found to be a difficult task, especially when adhering to the high robustness and low cost required from academic systems. Due to these difficulties, many institutions opt for using simulations and virtual representations as a substitute to physical production facilities [10].

The challenges of teaching future factory concepts are similar to that of teaching CIM. Hands-on experience is of great importance, while constructing and maintaining a suitable physical system facilitating such experience is not simple. However, the difficulties faced when coming to construct a system suitable for teaching future factory concepts are different from those previously incurred with academic CIM systems. The major difficulties in constructing systems suitable for teaching higher-level CIM concepts emerged from what were in fact the major CIM difficulties. The systems were extremely complex and were expected to be fully automatic. The major difficulties in constructing systems suitable for teaching future factory concepts stem from the need to augment production concepts with concepts from different disciplines and fields of knowledge, such as information systems and human factors. Information systems have evolved considerably in the past two decades, particularly in directions that require cross-organizational standardization and integration, which increase the complexity of their implementation in production settings. Furthermore, although the directions seem clear, many issues have not been resolved yet and the complete future factory paradigm has not been fully defined.

The integrated manufacturing technology (IMT) laboratory is a future factory facility currently being built in the department of Industrial Engineering and Management (IEM) at the Ben-Gurion University of the Negev. The main goal of the IMT laboratory is to facilitate teaching and research on the integration of future factory concepts, cutting edge technologies of shop floor automation, and organizational information systems.

The IMT laboratory is replacing a CIM laboratory established in 1993 [7, 11, 12]. The CIM laboratory was a fully automated robotic manufacturing facility with all classical CIM components: a central database, flexible manufacturing stations, computerized numerical control (CNC) systems, multi robot assembly, automatic guided vehicles (AGV) etc. The laboratory had a major impact on establishing the department of IEM at Ben-Gurion University as one of the leaders in robotics and CIM research. The laboratory was used for manufacturing research and teaching in both undergraduate and graduate courses, projects, and theses and served throughout the years as a major attractor to University visitors. The laboratory was used for demonstrations to various visitors including official delegations, University donors, colleagues, and youth in extra curriculum activity in the field of robotics. Two decades after its establishment, the equipment in the laboratory needed major reconstruction. The laboratory’s leading team decided to seize the opportunity and re-examine the core concepts on which the system was based upon. After careful examination of both current trends and teaching needs, a plan for re-initiating the laboratory as a multi-disciplinary future factory manufacturing laboratory has been launched. The main theme of the new laboratory is Integration. Concepts underlying the IMT laboratory come from the fields of production planning, intelligent automation, information systems, and human factors. More specifically the following issues shape the construction of the laboratory:

- Organizational information systems including ERP, SCM, CRM and PLM, and business intelligence.
- Intelligent system automation, including advanced robotics, image processing, sensor fusion, and self-learning capabilities.
- Human factors engineering, including human-machine interfaces at various levels of system automation and operator functionalities.
- Production planning and optimization, green manufacturing and sustainability.

IEM students take several information systems courses, including database design and management, system analysis and design, ERP and others. They also study ergonomics and human-machine interfaces. A major problem faced by such courses is demonstrating the link between the intangible information systems and the physical real-life organizational environment. The design of the IMT laboratory aims at the facilitation of such demonstrations.

The IMT laboratory will produce physical products where the main part of the production process will be a robotic assembly process. Machining will also be demonstrated yet at a lower level of sophistication. Additional processes will include robotic quality control, an RFID based storage system, and an autonomous robot based material handling systems. The autonomous robots will use a floor embedded RDIF system a navigation aid.

Digital factory methods will be employed for shop floor control. Station controllers will report real-time data to a central shop floor database. This database, in turn, will be connected to higher level information systems. We are currently considering the integration of an ERP system in order to demonstrate the use of shop floor data in enterprise management systems. In particular, we consider the integration of an ERP on-demand solution to demonstrate the applicability of software-as-a-service (SaaS) and cloud computing concepts. We also consider remote options, such as remote maintenance and remote order initialization. Such options will open the way for the demonstration of complex security-related issues.

Human factor methodologies will be employed for designing station controller interfaces and the monitoring screens of the laboratory control center. Green manufacturing concepts and product sustainability considerations will also be demonstrated (e.g., each station will include energy monitoring sensors).

We expect the laboratory to host at least 250 undergraduate students and about 50 graduate students each semester. Additionally, at least the same amount of researches, University donors, and youth groups are expected.

2 IMT COMPONENTS

2.1 Overview

The first type of product to be produced in the IMT laboratory is a 3D puzzle assembled from three sub-assemblies (Figure 1). The sub-assemblies (parts) may be made of several raw materials (wood, plastic) and are purchased from various suppliers. Bellow we detail the main components of the IMT laboratory.

2.2 Business plan

The IMT laboratory is an academic facility and it is not designed to make a profit for the department. However, simulation of a real business setting requires the development of a business plan. Therefore, for the construction of a complete production facility, it seemed imperative to form a business plan for the IMT laboratory. The initial incentive for developing the business plan came from the plan to introduce the laboratory into management-oriented courses, such as information systems management, that emphasize the importance of aligning technological objectives with business objectives. The laboratory serves as a major attractor for youth visitors to the University and, therefore, we decided to base the business scenario on a youth visitor center. A similar facility operates in the northern part of Israel as part of the Tefen industrial park museum[1]. A financial analysis showed that the construction of such an endeavour is indeed feasible. The option of actually constructing a for-profit youth visitor center in the department is a viable option, which may become a reality in the near future.

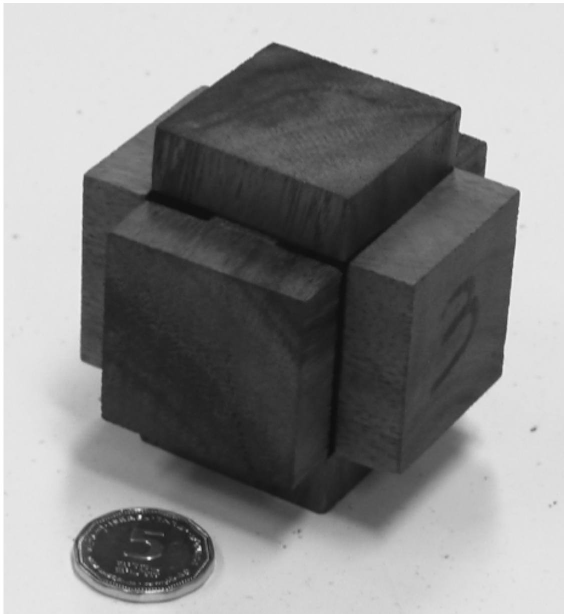

Figure 1 The fully assembled 3D puzzle

2.3 RFID

RFID plays an important role in future factory methodologies. As a highly integrated, low power and low cost technology, it facilitates system decentralization, where products can know their history and routings [3]. Studies regarding the value of RFID in the retail sector have already shown it can facilitate considerable savings [13]. It was therefore important to integrate an RDIF system within the IMT laboratory. The envisioned FRID systems will include the following layers:

- Production process monitoring and support of both automated and manual product retrieval from the RFID fitted storage facility.
- Support for tool placement monitoring through tagged tools and a RFID fitted doorway.
- Support of AGV navigation through RFID tags implanted in the factory floor

2.4 Information infrastructure

The information infrastructure for the IMT laboratory has been constructed using accepted system analysis methodologies. In particular, we have used entity-relationship diagrams (ERD) to depict the logical structure of the data. The general architecture is comprised of small-scale local workstation databases, connected through extract-transform-load (ETL) components to a central PLM database, to which product design and production planning data bases will also be connected. The PLM database is than connected to a data warehouse

[1] http://www.omuseums.org.il/default.aspx

(Figure 2). The databases will be implemented using Microsoft SQL server. The data warehouse will provide the required infrastructure for business intelligence (BI) and data mining applications, which will be used for control purposes and for gaining insight on the efficiency and effectiveness of production processes. In the future we plan to add ERP, CRM and SCM systems which will also be connect to the data warehouse.

The above infrastructure demonstrates the concept of “vertical” (or bottom-up) information integration, where real-time production data is utilized to support managerial decision making. However, we also aim at demonstrating the concept of “horizontal” information integration, where real-time production data is integrated with operational data generated by other business processes, such as procurement. For this reason, we are currently in the process of examining the implementation of a small-scale ERP system using the on-demand model.

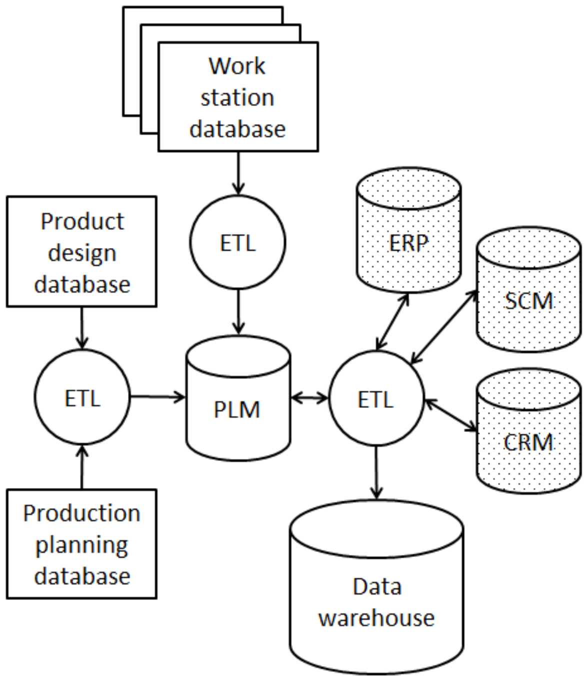

Figure 2 General layout of IMT databases. Dotted components will be added at the second development phase. ETL – extract transform load, PLM – product lifecycle management, ERP – enterprise resource planning, SCM – supply chain management, CRM – customer relationship management.

2.5 IMT layout and work stations

The IMT laboratory will be developed in three one year phases. The first phase is expected to end September 2011. The fully developed IMT laboratory is planned to have six manufacturing workstations (Figure 3): a storage station, a pre-assembly station, an assembly station, a production station, a quality control station, and a packaging station. Items are transferred between the workstations by an AGV system and a linear slide base. In the first phase we are developing the storage, pre-assembly, assmbly and packaging stations. In the second phase we will develop the quality control station and at the third phase we will developed the production station. The production process implemented in the IMT laboratory is mainly an assmbly process and it is based on kits. The parts are placed in dedicated positions in the kit tray in the pre-assembly station.

The storage station has two shelve racks. Each rack has five shelves. The shelves are equipped with an RDIF system. Items that are stored on the shelves include: boxes of raw material, bins for parts or fully assembled products, trays for kits to be assembled, and tools. Each of these items has an RFID tag. A human operator loads and unloads the shelves and the AGVs, i.e. the station operation is not fully automatic and the AGV can only park next to the shelve racks and wait until the human operator loads or unloads them.

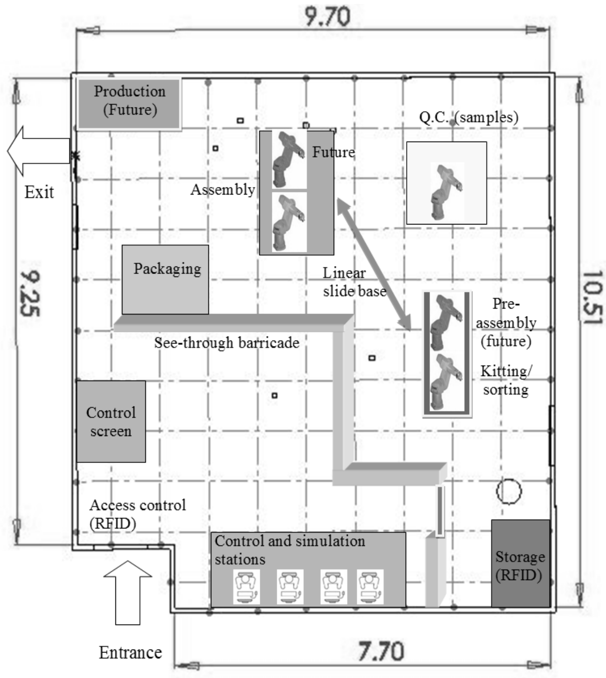

Figure 3 General IMT factory floor layout. Dark grey robots (in assembly and kitting station) and production station will be implemented in the future. The packaging and storage stations are services by human operators. The Quality control (QC), assembly and pre-assembly stations are fully automatic robotic stations.

The pre-assembly station has a robot, buffers, a camera, and a tray feeder. The station has several input buffers for bins with parts, a buffer for a bin with faulty parts and several buffers for trays. The robot loads and unloads the AGV with bins and it loads and unloads the linear slide base with trays. Trays delivered from the pre-assembly station are always full, i.e. have a kit with three parts ready for assembly and trays returning to the station are always empty. The robot performs kitting by taking one part of each type and placing it in the appropriate place in the tray. The part goes through a visual quality test before it is placed. Parts that do not pass the quality test are placed in the faulty bin. In the future the station will have an additional robot that will perform an additional part pre-assembly process. Several processes are currently being considered, e.g. gluing lower level sub-assemblies.

The assembly station has a robot, a camera, additional sensors (e.g. force sensors), a clamp, and buffers. The station has input buffers for trays, a faulty part buffer, and an output bin buffer. The robot loads and unloads the AGV with bins and it loads and unloads the linear slide base with trays. The robot assembles the parts from the active tray with the aid of the clamp. The assmbly process planned is nontrivial since it requires precision both in 3D positioning and applied forces. The assembled product undergoes through a visual quality check before it is placed in the output bin. Products that do not pass the quality test are placed in the faulty bin. In the future the station will have an additional robot. It will then be possible to compare single robot assembly and multi-robot assembly, where the two robots will cooperate to assembly the product. It will also be possible to explore robot task division, e.g. one robot performing loading/unloading operations and one robot performing assembly.

The quality control station will have a robot, a camera, various sensors, and buffers. The robot loads and unloads the AGV with bins. The arriving bins are placed in the input buffers, and after the tests are completed they are placed in the output buffers. The robot performs various quality tests on the parts and assembled products.

The packaging station is a manual station. The human operator loads and unloads the AGV with bins. Arriving bins are placed in the input buffers, the packaged products are placed in the output buffers. The operator packs the products from the input bins, weighs them, prints a delivery document and places the packaged products in the output bin. Faulty products detected by the operator are placed in the faulty bin.

3 INTEGRATION IN THE IEM CURRICULUM

3.1 Overview

The IMT laboratory will be used for supporting courses in the IEM department. In the first phase the laboratory is planned to be used for demonstrations in two mandatory graduate courses and for “hands-on” laboratory exercises in four elective and graduate courses as detailed in Table 1. Additionally the laboratory will be used for supporting forth-year projects and M.Sc. and Ph.D. theses. Additional courses will enter the laboratory in the second and third phase. General plans have been discussed with instructors of courses in statistics and production planning.

Table 1 Phase 1 Planned courses in the IMT lab

Course (lecturer)	Semester - student number	Level	Activity
Man machine systems	B-30	Graduate	Laboratory meeting; Mini project
Computer integrated manufacturing systems	B-15	Graduate	Laboratory meeting; “Hands-on“ homework assignment
*Foundations of robotics in production systems	A-15	Graduate	Laboratory meeting; Homework assignment
Advanced topics in data management	A-30	Undergrad (elective)	Laboratory meeting; Homework assignment
Automation	A & B -120	Undergrad (3rd year)	Laboratory tour.
Introduction to information systems	A & B -120	Undergrad (2nd year)	Laboratory tour; Class example

* Part of INTRO EU international education project.

Man machine systems (Graduate)

The course deals with human factors issues in human machine system design. The laboratory meeting is a regular teaching session (3 hours), which is comprised of the following parts:

- A short lecture about the laboratory.
- The students are divided into workgroups. Each workgroup is assigned to a workstation. The students learn how to operate the station using the station work manual. Each group has to reset its workstation (start-up). Then, each group prepares a poster about the station interface, its strong and weak points.
- The students tour between all stations where each group explains the operation of its station to all other students and describe the station interface.
- Summary of the experience and concluding remarks.

Mini project - The students have to design an interface for the station on which they had worked in the laboratory meeting. In addition to the laboratory meeting they can interview the laboratory technician who plays the role of a station operator. The interview is time-constrained (20 min) and the students have to be well prepared for it.

Computer integrated manufacturing systems (graduate, mandatory for undergrads in the production systems track)

The course discusses implementation of different technologies in CIM and issues in integration, control and management of such systems. The laboratory meeting is a regular teaching session (3 hours). The homework assignment is given prior to the laboratory meeting. The laboratory meeting is comprised of the following parts:

- A short lecture about the laboratory with a demonstration of the production operation and presentation of the homework assignment.
- The students are divided into workgroups. Each workgroup is assigned to a workstation. The students learn how to operate the station using the station manual.
- The students tour between all stations where each student suggests ways to improve station performance. The instructor assists the student in selecting one of the suggested improvements for implementation in their homework.
- Summary of the experience and concluding remarks.

Homework assignment – This assignment is one out of three course assignments. The students implement an improvement to one of the production process and test the impact of their improvement.

Advanced topics in data management (undergraduate, elective)

This course deals with the implementation of data warehouses and their use for BI and other decision support applications. The aim of the collaboration with the laboratory is to demonstrate the implementation of BI solutions in industrial environments, and to use BI solutions for detecting causes for failure and potential process improvement. Students will participate in a mandatory laboratory meeting that will demonstrate data collection and integration in a production process, toward a better understanding of the business and the process. As a follow-up, the student will receive a complementary homework assignment, based on a simulation of the data collected during the process, and will be asked to analyze the data, visualize it in a manner that will permit better understanding of quality-deterioration causes, and recommend process improvements accordingly. The homework assignment together with a simulation of the laboratory aimed at producing the required data records are currently under development.

Foundations of robotics in production systems (graduate)

This course is currently re-designed after a long period in which it was not given. The material will include basics of both kinematics and dynamics of robotic systems. The course will have a laboratory meeting and homework example based on the robots and robotics processes in the IMT laboratory.

Automation (3rd year undergraduate)

The course surveys plant automation and computation. Course topics include actuators, measurement methods and sensors, computerized control, programmable logic controllers, and computerized numerical control. Toward the end of the semester, the students have a of the advanced production laboratories (IMT laboratory, telerobotics laboratory, intelligent systems laboratory, and mobile robotics laboratory). The class is divided into two consecutive tours. Each tour is 1.5 hours long. Within each tour, the class is further divided into two groups (thus each sub-group has about 30 students). The students come to the IMT laboratory for about 30 minutes, during which they hear a detailed explanation of the automation equipment and sensors used in the laboratory. A question about the tour is integrated in the final course exam.

Introduction to information systems (2nd year undergraduate)

The course deals with information technology and information systems. It relies on assignments in which the students are asked about the information systems needs of various (mostly fictitious) organizations. One of the assignments in this course will be based on the IMT laboratory. As part of the assignment, the students will come for a laboratory tour and demonstration. This activity will advance the students' understanding of how information systems can support the execution and management of real organizational processes.

3.2 Quantifying laboratory activity

The IMT laboratory is expected to be a major contributor to the excellence of both research and teaching at the IEM department at the Ben-Gurion University. We expect the laboratory to host about 250 undergraduate students and about 50 graduate students each semester. Additionally, at least the same amount of visitors and youth activities are expected.

The following measures will be used to monitor laboratory activity:

1. The number of students in courses affiliated with the laboratory each semester.
2. The number of 4th year projects and graduate students affiliated with the laboratory each year.
3. The number of youth related activities taking place in the laboratory each semester along with the number of participating pupils.
4. The number of delegations hosted by the laboratory each semester.
5. The number of research grants associated with activities performed in the laboratory.
6. The number of publications associated with activities performed in the laboratory.

4 CONCLUSION AND FUTURE WORK

The IMT laboratory is a future factory facility currently being built in the department of IEM at the Ben-Gurion University of the Negev. The facility is carefully planned to facilitate teaching of future factory concepts in various related courses for different disciplines, including intelligent systems, production planning, information systems, and human factor engineering. The laboratory is designed to demonstrate the application of state-of-the-art concepts and technologies, such as RFID, BI, and SaaS. The IMT laboratory will, therefore, demonstrate how various disciplines and advanced technologies can be integrated to create the future factory.

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