Design and Implementation of an Automated Cell for Injection Molding

Winston F. Erevelles
Robert Morris College

Abstract

The current paper describes a senior-level course in Robotics taught by the author at Kettering University in the Spring session of 1999. The course was taught in project form and dealt with the design and implementation of an automated manufacturing cell for molding, unloading, and degating injection molded parts. The class had 11 students majoring in Manufacturing Engineering, Mechanical Engineering, and Applied Mathematics. Salient points of this paper include the original concept of laboratory integration for deeper understanding of the subject matter, the funding process, faculty collaboration, student grant proposals to obtain equipment needed for the project, and the design and integration of cell components.

I. Introduction

The manufacturing engineer of today and the coming century needs to be an individual with a variety of technical and interpersonal skills. S/he will serve her/his community in diverse roles as technical specialists, operations integrators, and enterprise strategists. What industry needs from its graduate engineers is the ability to thrive in environments that are characterized by people working in multifunctional interdisciplinary teams[1].

At Kettering University this approach began a few years ago with various faculty members working to integrate their laboratories and the curriculum. The primary driver for this initiative was the provision of a seamless curriculum to the student body in contrast to the traditional approach where learning is often experienced in fragmented fashion. Grants from the National Science Foundation were instrumental in obtaining some of the equipment used for this method. Two of the laboratories that welcomed this change were the Computer Integrated Manufacturing (CIM) and Polymer Processing facilities.

The CIM laboratory features material handling systems such as a Litton AS/RS, a Litton AGV, and conveyors from Bosch and Flex-link. The sixteen material handling, assembly, and process robots include manufacturers such as Fanuc, Adept, Unimation, Seiko, IBM, and Mitsubishi. Industrial grade CNC equipment includes a Kryle VMC-500 vertical machining center and a Mazak Quick Turn 8 turning center along with three Denford benchtop machining/turning centers. Inspection facilities are available locally in the form of an Adept machine vision system. Auto ID equipment is available in the form of Allen Bradley bar code scanner and RF tags from Balogh. The facility features programmable logic controllers form Allen Bradley, Modicon, and GE. Twenty-five high end personal computers and various workstations provide the facility with its computing capabilities. The facility shares Cincinnati Milacron injection molding machines and a SLA-190 rapid prototyping machine with the neighboring Polymer Processing facility.

The Polymer Processing laboratory houses a thermoformer, an extruder, and three injection molding machines. In addition to this process equipment, there are also facilities for mechanical testing of ASTM standard specimens. Polymer processing laboratory investigations focus on the relationships between process parameters and part quality. Mechanical tests are performed on the molded parts and measurements are made to assess shrinkage.

The paradigm shift advocating a continuum of experiences sought to provide students (individual and in teams) with integrated experiences that reinforce and correlate subject matter learned in different courses. An expected outcome was that snapshots of localized information would be woven into a fabric of engineering knowledge and interpersonal skills that would then be applicable to a variety of manufacturing problems and situations in the workplace.

II. The Robotics Course

IMSE-490: Robotics is a senior-level course taught at Kettering by this author, and is one of three courses in the area available at the university. The Mechanical and Electrical Engineering departments offer the other two courses. The Mechanical Engineering department's offering focuses on the kinematics of robotic manipulators while the course from the Electrical Engineering department focuses on the control of the manipulator. The Manufacturing Engineering course in Robotics addresses basic concepts of industrial robot theory and application. The primary purpose of this course is to provide the participant with a broad practical knowledge base in the field of robotics. Using this information, students are able to select, interface and integrate robots for applications such as material handling, processing operations, and joining operations, inspection, and non-manufacturing tasks.

The specific learning objectives for the course are:

1. Understand how to specify, develop, and implement robotic applications and work cells for various applications such as material handling, processing, assembly, and inspection
2. Learn and demonstrate the application of sound engineering principles in the programming and operation of industrial robots
3. Develop solutions to integrate the robot with other robots or automation devices
4. Develop solutions for process monitoring and supervisory control by a host processor (computer or PLC)
5. Understand the theory and application of machine vision systems for inspection and robot guidance
6. Learn to specify after-market tools and components that may be used to extend the capabilities of industrial robots. These include end effectors, hand exchangers etc.

7. Get familiar with the theory and application of ANSI/RIA Robot Safety Guidelines to various robot work cells.

Over time the syllabus has been developed in response to these learning objective and the course has evolved in response to industry needs and the direct feedback of engineers and other personnel who have taken this course when offered by the author through the Society of Manufacturing Engineers.

In its traditional form, the course covers a lot of ground and is typified by three lecture sessions followed by a laboratory every week. Experimental work in the laboratory is done in serialized fashion and seeks to expand upon theoretical concepts. While the coverage is comprehensive in nature, students are often burdened with minutiae and do not fully appreciate all aspects if the integration of robots into the plant environment. To remedy this problem, the course sought to incorporate smaller projects that were initiated well into the semester. Discussions with industry personnel led the author to offer the robotics course in a 100% project format in the Spring of 1999.

III. Robotics – the Project Approach

In mid-1997, the university hosted Mr. Eric Mittelstadt – President and CEO of Fanuc Robotics and also an alumnus of the institution. During the course of his visit, Mr. Mittelstadt guest lectured the Robotics class and toured facilities for automated manufacturing. Following that visit, the author submitted a proposal targeting the donation of robots to the facility. The co-investigator for this effort was Professor Laura Sullivan – a faculty member working in the areas of Engineering Materials and Polymer Processing. The purpose was the automation of one of the Cincinnati Milacron injection molding machines obtained using NSF funding. Fanuc Robotics donated two robots to the university in the third quarter of 1997. These included an S-12 six-axis articulated robot and an Arc Mate Mini five-axis articulated robot along with controllers and appropriate I/O modules. The robots were initially used as an instructional and recruitment tool and then served as a test bed for independent projects and research.

In the Spring session of 1999, the author taught Robotics to a class of eleven students with majors including Manufacturing Engineering, Mechanical Engineering, and Applied Mathematics. The class had one student from Fachhochschule fur Technik Esslingen, Esslingen, Germany majoring in Production Engineering. The students worked at co-op employers that spanned the manufacturers of automobiles, bearings, and material handling equipment. Student backgrounds also included one employee of a systems integration company.

The first meeting of the class served as the introduction to the course and the kick off for the project. The students were charged (and challenged) with the design and implementation of a robotic cell that would unload and degate parts manufactured on the injection molding machine. The key components of the cell – i.e. the injection molder and the robot had to lend themselves to stand alone operations to support other classes, maintenance, and recruitment activities. Products processed by the cell had to be transported to a remote assembly cell via AGV and the scrap generated by the cell had to be disposed. The overall cell had to be fully safeguarded and in compliance with ANSI/RIA 15.06 standards. Students buy in to the project was an easy process once the objectives of the course and goals of the project were explained.

All theoretical and laboratory topics were covered with this specific project - automation of injection molding, as the central focus. These included topics such as robot safeguarding, end effector design, controls and integration, robot programming, and process monitoring and sensor integration that were fully listed in an earlier section. Four groups were formed to address the following areas: Cell design and safeguarding; end effector design; degating and material handling; and controls, integration, and programming. The following table illustrates the responsibilities assigned to each group and the number of students operating in each group.

Group Function	**Responsibilities**	**Size**
Cell design and safeguarding	Design and implement methodologies to safeguard the injection molding cell and provide access for maintenance and programming. Design and implement cell layout – special requirements include future expansions for a hand exchanger stand and additional tooling for degating	3
End Effector Design	Design and implement end of arm tooling to include safety joint, extension arm, robot gripper, and fingers for machine loading and degating	3
Degating/AGV	Design and implement methodology for degating molded parts and disposing scrap Design and implement AGV interface to the cell	2
Programming, Controls, and Integration	Design and implement the interface between the robot, the injection molder, and a PLC. Design control logic & operator interfaces for the cell	3

The author and the laboratory technician adopted a predominantly advisory role where they were involved in all discussions. The team itself was led by a student project manager who was responsible for the execution of the project according to the plan, within the time allocated for the project, and within the budget allocated for the cell. Since the area of injection molding and the specific equipment used for the process was new to some of the class, a special session was led by Professor Gwan Lai of the department to familiarize the participants with the process and the machine.

In each of the major areas identified in the preceding table, the following strategy was adopted[2].

- Discussion of underlying theory
- Discussion of current practice and developments (Aided by literature surveys, plant visits, internet searches, and vendor involvement)
- Development of application-specific functions required for the area in question
- Development of multiple feasible solutions
- Convergence on the optimal solution through the analysis and evaluation of the competing solutions

- Final evaluation of the selected solution from the standpoint of feasibility, safety, economy, and flexibility with respect to future expansion
- Laboratory testing of the selected solution
- Implementation of solution in the automated cell

It should be noted that all eleven students were involved in all aspects of the project at the conceptual and design stage. The methodology was based on conformance to standards, the usage of sound engineering principles, and mathematical analyses where applicable in the design process. The group associated with the specific task/area was finally responsible for the implementation of the selected methodology. Implementation of each area of the project involved interaction with plant maintenance personnel at the university, the usage of various pieces of equipment for mechanical, electrical, and electronic fabrication, interaction with vendors and purchasing personnel at the university, and the technicians associated with various university facilities. Figures 1 shows the overall layout of the cell while Figures 2 and 3 are photographs of the cell.

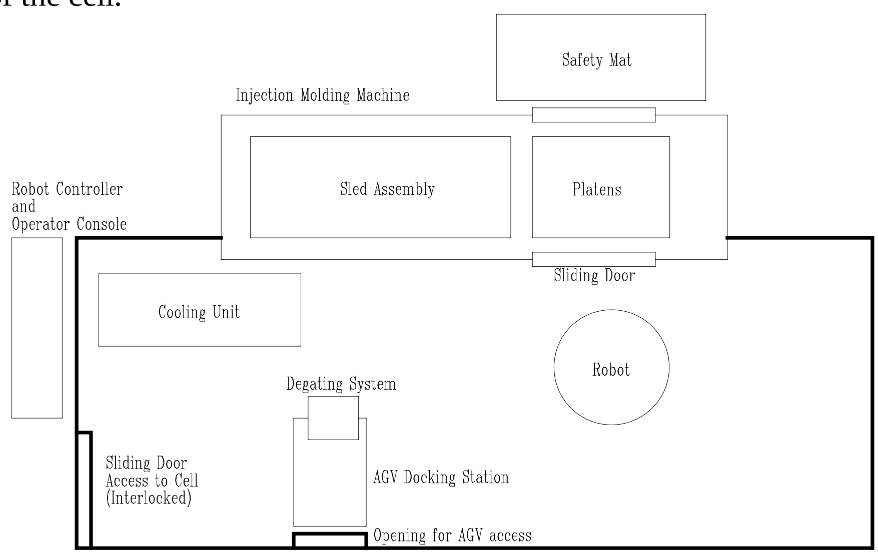

Figure 1. Layout of Cell

One of the challenges facing the students was the dual-purpose nature of the injection molding machine – manual usage for instruction in Polymer Processing and automated operations for the Robotics project. To achieve this duality and still maintain a safe operational environment, the group decided to do the following:

(a) Implement a selector switch at the operator console for mode selection – automated vs. manual
(b) Incorporate a pressure-sensitive safety mat in front of the machine (see Figure 1) and
(c) Protect the robot side of the cell with 8'-high perimeter guarding from American Machine Guarding. Access to the cell was achieved using an interlocked sliding door

Violation of any of the above systems listed above brings the robot and the injection molding machine to a safe controlled stop requiring human intervention. The layout of the cell followed extensive reach studies – here attention was directed towards safety, collision avoidance, cell throughput, and the avoidance of singularities. Since the parts manufactured in the cell have to be transported by an Automated Guided Vehicle (AGV), an access opening was created in the perimeter guarding system. The operator console and the robot controller were placed so that an operator has optimum visibility of the cell. In the development of safety procedures, the ANSI/RIA 15.06 standard was followed[3]. This resulted in the implementation of hardware and software for controlled and safe operation of all the equipment in the cell. This includes the perimeter guarding fence, safety mats, emergency stop pushbuttons, electrical interlocks, awareness devices, hard stops, and event-driven robot and control programs.

Figure 2. Inside the Cell

Figure 3. View from the Injection Molder

The end effector design had to address the safe and repeatable extraction of parts from the injection molding machine and tending the degating apparatus. It was decided that the following components would be incorporated (see Figures 4 & 5) into the end-of-arm-tooling (EOAT).

(a) Safety joint to protect the wrist in case of collisions. A spring loaded safety joint was specified and obtained from MDI Wristwatch
(b) Extension bar to keep the robot wrist outside the platens at all times. This was achieved using a length of extruded aluminum bar from 80/20 Inc.
(c) Robohand RP10 gripper body. The gripper is actuated pneumatically and allows for enhancements such as finger position detection. The group decided to recommend this feature for incorporation at a later date
(d) Gripper fingers. These aluminum fingers were custom machined to match the taper of the sprue and featured protrusions or “teeth” to prevent slippage during part extraction. The group also decided to incorporate an emitter-detector pair of sensors in the fingers for part presence sensing.
(e) Interface plates to couple all of the above components

Figure 4. Robot EOAT

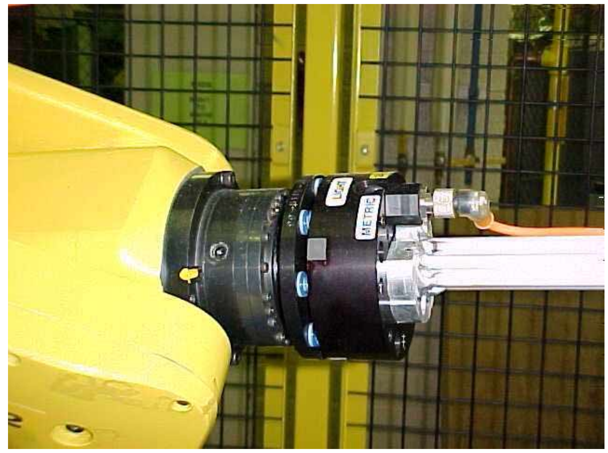

Figure 5. Safety Joint

The degating of parts was done using an apparatus similar to the one shown in Figure 6. The primary difference is that the actual apparatus used in this application featured solenoid-controlled actuation. The apparatus was mounted on the AGV docking station in the cell along with a chute for degated parts. The robot was programmed to present the parts to this apparatus. The actuation of the gate cutter causes degated parts to slide down the chute into the AGV tote and the sprue is then dropped off at a recycle bin and sent for regrinding. This group had to incorporate a new station stop into the AGV's configuration program. In addition, they also had to implement location codes and the guidepath for the AGV to integrate it with the cell.

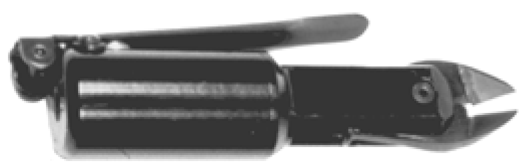

Figure 6. IMS Gate Cutter

The controls group integrated a bank of solid state relay-based bank of I/O points on the injection molder with the robot controller, and an Allen Bradley SLC500 programmable logic controller (PLC). The group automated the operations of the sliding door on the injection molder and also incorporated all the safety equipment and devices into an integrated safety system for the cell. In view of the various sub-systems that were part of this automated cell, the PLC was introduced for process monitoring and control. The group used the Teach Pendant Editor to develop the robot program for part extraction and degating.

The students adopted a very aggressive and pro-active stance as the project got underway. Student proposals to various vendors led to the donation of a pedestal to mount the robot and the fence that served as the perimeter guard for the robot. A similar proposal led to the provision of the robot overload protection device at cost. Over the course of the term the students had to deal with tardy deliveries, incorrect shipping lists, incorrect parts, organizational inertia, some personality conflicts, and inter-group communications.

In addition to traditional assessment measures such as quizzes, examinations, and laboratory reports, a significant percentage of the overall grade was tied to the project. Project assessment measures included the final evaluation of the project by the author, quality of the documentation, self evaluations conducted on an ongoing basis by the class, peer evaluation of all group members, and the timely delivery of progress reports and other deliverables.

IV. Conclusion

At the end of the 12-week term, students had a fully functional cell that was capable of untended operations as specified in the original project definition. Working in 4 teams - each of which had 2-3 students at its core, this diverse body of students was completely responsible for all technical aspects of the project, communications, project management, teamwork/conflict resolution, and procurement issues.

What was noteworthy about this approach was the iterative nature of taught theory, library and vendor research, laboratory experimentation for the feasibility of ideas, and the ultimate implementation in the project. The delivery of the course in the project format placed significant demands on all concerned (students and faculty) in terms of the time and effort necessary to participate or teach in an effective manner. However student evaluations and comments made during the debriefing session at the end of the project pointed to a very high level of satisfaction with the project.

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WINSTON F. EREVELLES
Dr. Winston Erevelles is a Professor and Head of the Computer Integrated Engineering Enterprise program at Robert Morris College in Pittsburgh, PA. His most recent assignment was at Kettering University in Flint, Michigan where he was an Associate Professor and Director of the Manufacturing Engineering program. His teaching and research interests are in the areas of Manufacturing Processes, Automation, Robotics, Rapid Prototyping and Computer Integrated Manufacturing. He has worked as a Manufacturing Engineer and Plant Manager at Mykron Engineers, India. There he was responsible for advanced machining, grinding and honing systems; manufacturing Fuji diesel engine components including cylinder liners, valve seats, and exhaust valves; and for line boring operations on off shore oil platforms. He is a recipient of the 1996 Society of Manufacturing Engineer's Philip R. Marsilius Outstanding Young Manufacturing Engineer Award, the 1996 GMI Alumni Association Award for Outstanding Teaching in Manufacturing Systems Engineering, and the 1997 Rodes Professorship at Kettering University. He is an active member of SME, ASEE, and AAAI.