Curriculum Development in Construction Automation

Laura Demsetz
Assistant Professor
Department of Civil Engineering
University of California
Berkeley, CA 94720

Ronie Navon
Visiting Assistant Professor
Department of Civil Engineering
North Carolina State University
Raleigh, NC 27695-7908

SUMMARY

Research in construction automation has become fairly well established. Teaching the subject to tomorrow's researchers and practitioners has, however, received little attention. This paper discusses some of the issues encountered in planning a comprehensive course on construction automation. Two graduate level courses are presented as examples; it is hoped that they will provide the starting point for further discussion. To solicit the opinions of a larger number of educators and researchers, a survey on issues relevant to curriculum development is included.

Key words: automation, construction, curriculum development, education

INTRODUCTION

This symposium marks the seventh time researchers from around the world have met to exchange ideas on advanced technologies for the construction industry. Significant progress has been made — in the identification of construction tasks best suited to automation, in the development of automated equipment, and in the use of computers as simulation and management tools. Increasingly, research is yielding results that can be implemented in the field.

Tomorrow's construction leaders should be aware of available and developing technology, and should understand how to use it appropriately. One way to accomplish this is through formal coursework in construction automation. Although research in construction automation has become well established, teaching in this area is still relatively new and not yet well-defined. Should automation be viewed as an extension of current practice, or as something fundamentally new? Should students understand the technical details of automated systems? These questions, among others, faced the authors as we each undertook the development of a graduate level course in construction automation. This paper presents our thoughts and experiences to date.

Teaching Construction Automation

As with any new course, there is not yet a traditional approach to the subject of construction automation. Issues of scope, content, and level must be carefully considered. Curriculum development is complicated by the fact that construction automation is a relatively new and rapidly changing field. While the use of highly automated systems is common for some aspects of construction, such as tunneling, for most applications automated equipment is still largely a topic of research. Information on cost, productivity, and reliability is not readily available. Automated equipment can not, at present, be "taught" in the same way as more traditional construction equipment.

In planning a course on construction automation, the backgrounds, needs, and expectations of the students must be considered. Most students in a construction management graduate program will have an undergraduate degree in architecture, construction, or civil engineering. They will likely have had a course in engineering economics, along with some exposure to construction operations. Many will have had some construction experience. Few students in a construction management program, however, will have had exposure to mechanical design, electronics, or control theory. This complicates the presentation of the technical aspects of automated equipment.

One of the difficulties of teaching in an emerging field is striking an appropriate balance between research and practice. Although a few students may plan a career in research, most anticipate a position in construction management. The former group is more likely to become involved in the development of automated systems; for them, a focus on the identification of potential applications of automation, on system design issues, and on ways to transfer research to practice may be most relevant. The members of the latter group are likely to be in a position to use automated equipment as it becomes commercially available; for them, issues of performance, economic evaluation, training, and maintenance will be important. Ideally, a course on automation should touch upon both research and practice. The result should be practitioners who are aware of the technologies under development and are on the lookout for research opportunities, and researchers who have an appreciation for the constraints of practice and a knowledge of previous research efforts.

Related Courses

Most mechanical and electrical engineering programs offer three types of courses relevant to automation and robotics. Courses on *microprocessor-based systems* cover the core of an automated system. The student acquires an understanding of how programmed instructions are translated into the movement and control of physical systems. These courses typically require experience in computer programming. *Robotics* courses are concerned with a higher level of automation, but are in a sense more specific, dealing with a particular type of automated system. Topics include programming, path planning, and efficient computation of kinematics. Programming experience and an understanding of dynamics are prerequisite. In *manufacturing* courses, robots and other automated equipment are treated as components of a larger system. Based on available components and an understanding of fabrication processes, students undertake the design of efficient production systems.

Courses in construction automation will most likely combine various aspects of the above courses in the context of construction applications. The balance between the details of operation and development (found in courses on microprocessors or robotics) and the application of automation within a larger production system (found in manufacturing) is likely to change as the field of construction automation matures. Consider the example of computer applications in construction. When software for estimating and scheduling was new, much attention was given to software *development*. As more packages became available, the emphasis shifted to the *application* of software as a project management tool. For now, development issues seem to be an important part of a course on construction automation. However, we anticipate a similar shift from development to application as experience with the automation of construction processes increases. Current treatment of traditional construction equipment provides one model: capabilities and applications are described in the classroom and perhaps through additional demonstrations. Courses in computer-aided education provide another model: applications are described, but hands-on experience is incorporated as well.

CURRENT OFFERINGS

One approach to teaching in construction automation, presented by Warszawski and Argaman[1], emphasizes laboratory experiments. The first course described in this paper takes a similar approach; the second places less importance on the laboratory. Both courses reflect recent progress in the field. The syllabus for each is shown in Figure 1; these are presented not as the definitive curriculum, but rather as a starting point for further discussion.

Current Offering at North Carolina State University

One of the authors is currently teaching a course entitled Construction Automation and Robotics at North Carolina State University (NCSU). The course includes the following elements:

- Course introduction and overview of the state-of-the-art in construction automation (accompanied by video clips).
- Classification of construction technologies, the need for automation in construction, the prospects in introducing automation to construction, and social and economic aspects.
- State of the art review and critical analysis, performed by the students through a search in literature, company brochures and video tapes.
- Robotic technology, as a comprehensive case study of an automated production system.
- Robotic laboratory, in which the students have two major assignments.
- Other automated systems in construction, such as expert systems, automated managerial tools, automated data acquisition, etc.

In addition to lectures, the course includes

- Exercises and small laboratory assignments, which accompany and substantiate the progress of the theory in the lectures.
- Critical analysis of existing construction applications, in which the students are required to report about existing automated systems, like an on-site automated system, off-site automatic production, etc. The report is to include, at least, the following elements:
  - Description of problem to be solved (motivation).
  - The guiding philosophy for the solution.
  - Description of application and specifications (hardware and programming components, methods, etc.)
  - Achievements.
  - Critical review (including the student's contribution and opinion).
- Major laboratory assignments:
  - Programming a robot to perform a complete task, including conditional operations based on sensory feedback. The required programming method is parametric, which is typical to construction needs.
  - Off-line programming with the aid of graphic simulation.

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1 Warszawski, A. and Argaman, H.: Teaching Robotics in Building, *Proceedings of the Fourth International Symposium on Robotics and AI in Building Construction*, Haifa, Israel, June 1987, pp 274-286.

- A case study, in which students design a schematic workstation to automate an on-site construction task. The students suggest a construction technology which lends itself to automation, design the automated system conceptually, select its components, and perform an analysis to check for economic feasibility.

There are 10 students in the course. One is a doctoral student, 8 are masters students majoring in construction, and one is enrolled part-time. A small (non representative) survey conducted among these students, at the very beginning of the first class, indicated their expectations from the course. Some of the typical answers are quoted below -

- To learn more about a new and fast growing field of Civil Engineering in general and construction specifically.
- To get familiarized with the potential of Construction Automation, hoping to capitalize on it.
- To become more familiar with upcoming technological advances in the construction industry, and their future impact.
- To broaden my horizons and prepare myself to expect the unexpected.

As this article is written, the course is in progress. It it difficult, at this stage, to evaluate the extent to which goals are being met. However, the general feeling is that the students enjoy the course very much (in spite of an exceptional workload) and are developing a more open minded approach to problem solving.

Current Offering at University of California, Berkeley

The other author is currently teaching a course entitled Automation in Construction at the University of California, Berkeley (UCB). This course covers recent developments in construction automation. The emphasis is on understanding the capabilities of available and developing technology so that the appropriate equipment, materials, and method can be selected for a particular construction project. Lectures on automation in manufacturing, prefabrication, inspection, and automation in construction (both off- and on-site) provide exposure to available technology. Lectures on productivity, human factors, and economic feasibility provide the means to evaluate this technology. Case studies provide more detail on specific applications, and address obstacles to the implementation of new technology. In addition to lectures and case studies, the course has included several field trips:

- tour of a truss prefabrication facility
- demonstration of partially automated earthmoving equipment
- demonstration of advanced computer applications developed in the R&D group of a major construction firm
- demonstration of a prototype machine for automated highway maintenance
- demonstration of a remotely operated vehicle for underwater inspection

Students are required to complete two major projects:

- Investigate and report on an existing example of automation in construction or manufacturing. Students are to
  - select an existing example of automation in construction or manufacturing,
  - describe the operation prior to automation,
  - discuss the issues important in planning for the introduction of automation,
  - describe the automated system (components, control strategy, etc.),
  - discuss and evaluate the system's performance in terms of production rate, reliability, owner/operator's satisfaction, and
  - suggest improvements to the system.

- Propose a new system that will improve productivity in a construction task. Students are to
  - select an existing construction task for which automation may be beneficial, and justify the selection,
  - analyze current practice (e.g. materials, method, labor requirements, safety issues, costs),
  - propose conceptual designs of several systems that could improve productivity,
  - carry out a rough assessment of the technical and economic feasibility of each proposed system,
  - carry out a more detailed assessment for the most promising system, and
  - make recommendations for future work.

Four doctoral students are enrolled in the course. As with the course offered at NCSU, students were asked to fill out a brief questionnaire. Responses to the question "What do you hope to learn in this course?" included

- Areas of need and opportunity for improvement in the on-site and off-site construction process.
- Human-computer-machinery interaction in construction; consequences of automation – is it that important?
- Need-based, technological, and economic feasibility; social problems, including attitudes of labor and management; areas with greatest potential for automation.
- A method to determine in advance whether or not a certain automation effort will be successful; what's new and what's coming.

It is too early in the term to gauge how well these goals are being met. Thus far, the field trips and case studies seem to be the most successful aspects of the course. The issue of estimating "intangible" benefits has proved to be of interest as well. In planning the course, it was assumed that students would be contemplating either a career in construction management or a career in research (most likely in an academic environment). An interesting third option has emerged, however. At least one of the students has considered forming a company to develop construction tools and equipment. To accommodate and encourage this sort of entrepreneurial spirit, a discussion of the product development and patent process may be included in the course next year.

A Comparison of Current Offerings

The courses described above share much common ground. Both devote considerable time to the motivation for increased automation, to the economic analysis of automation, and to a discussion of the state-of-the art. They differ in two main respects. The first is most likely a function of the other courses available in the respective programs. Computer applications are discussed in greater detail in the course at NCSU; at UCB, a separate course is devoted to this topic. Similarly, prefabrication and inspection are included in the UCB course in part because they are not covered elsewhere in the curriculum.

The second difference is more substantial, and at first glance appears to represent a difference in philosophy. The NCSU course includes a laboratory component; students program a tabletop robot and use a computer for graphic simulation. The lab sessions provide valuable hands-on experience and helps dispel myths about the potential for automation using robots. In the UCB course, the term "robot" is deliberately avoided; emphasis is placed on the development and selection of appropriate equipment, whether that equipment be traditional, automated, or robotic. Upon further consideration and discussion, it appears that both approaches have the same purpose, that is, to encourage students to consider a variety of technologies in addition to those traditionally used.

A SURVEY OF CONSTRUCTION EDUCATORS

Many questions arose in developing the courses described above. The answers are not straightforward, both because the topic is advanced technology in an industry with a conservative reputation, and because the course has no heritage. The authors first approached each other seeking advice. The ensuing discussions showed the similarities and differences in our approaches to teaching. However, many of our questions remain unanswered. To solicit the opinion of the construction community, we developed a survey, an abbreviated version of which is shown in Figure 2. Many construction management programs have neither the resources nor the expertise to support a course dedicated to automation and robotics. It is hoped that, in addition to providing insight into an appropriate syllabus for a course in construction automation, the results of the survey will be helpful to those who may wish to incorporate selected topics into more traditional construction courses.

A question germane to a course in construction automation is whether automation should be viewed as an extension of current practice, or as something fundamentally new. Automation might be viewed as distinctly different from current practice for several reasons. First, the technology is new, and has been treated as such in other industries. Second, automation can best be viewed in the context of an integrated system; construction equipment has traditionally been considered in a more isolated manner. Third, while conventional equipment is by definition well accepted, the introduction of automated systems may well be resisted by both labor and, to a lesser extent, management. Automation may thus warrant special treatment in a construction program.

Should construction students be taught the technical details of automated systems? Is a laboratory component essential? Few construction programs give students hands-on experience in operation of construction equipment. However, an understanding of the technical aspects automation may help determine appropriate applications. Hands-on experience may further clarify the capabilities and limitations of automation and robotics.

Another important issue is the scope of the course. The authors share the opinion that the term automation is not restricted to on-site production alone. Rather, it is relevant to the total construction process, from planning and design through operation of the facility. Are topics such as the use of computers in scheduling, estimating and control systems, expert systems, and automated data acquisition systems appropriate? The answer will of necessity depend upon the other courses offered in a particular program.

The survey described here has been sent to a sample of colleges and universities with construction programs. Included in the sample are schools that emphasize research and schools where the focus is teaching. The authors welcome input from all sources, and invite readers of this paper to either complete the abbreviated survey in Figure 2, or to contact us and obtain a copy of the full survey. After these responses are analyzed, we intend to make the results widely available to our peers. In addition, we hope to conduct a similar survey of construction practitioners.

SUMMARY

Construction automation is a dynamic field. The courses described here represent the authors' efforts to capture its essential elements in a one semester graduate course. While the goals of these courses are similar, there are several differences in content. We present them in the hopes of starting a broader discussion on curriculum development, and look forward to receiving comments, both through the survey and in person.

Construction Automation and Robotics North Carolina State University	Automation in Construction University of California, Berkeley
COURSE INTRODUCTION introduction, overview, video clips	INTRODUCTION overview, terminology, sensors, actuators, controllers
MAJOR FACTORS OF CONST. AUTOMATION need for automation, prospects, obstacles classification of construction technologies	BACKGROUND productivity, human factors issues, design and evaluation "methods"
AUTOMATION AND ROBOTIC TECHNOLOGY definitions and classification, robot anatomy and components	ECONOMIC FEASIBILITY estimating costs and benefits at various stages of development, "intangibles"
ROBOT MOTION ANALYSIS & CONTROL kinematics, path control, dynamics, control concepts, actuators and feedback components, power transmission systems	SENSORS AND INSPECTION sensors, non-destructive evaluation, data acquisition, examples of senors in existing automated equipment
LABORATORY SESSION demonstration, operating instructions, students' exploration	AUTOMATION IN MANUCTURING history, types of automation, case study (metal cutting with laser)
AUTOMATED SYSTEMS FOR CONSTRUCTION development approaches and methodologies, case study	OFF-SITE AUTOMATION IN CONSTRUCTION information processing (computer applications), materials processing, case study (concrete batch plant)
END EFFECTORS AND SENSORS end effectors, robot/effector interface, sensors, use of sensors in robotics	PREFABRICATION benefits, obstacles, degree of automation, examples
PROGRAMMING AND MOBILITY languages, programming principles, simulation and off-line programming, robot mobility, AGVs	STUDENTS' PRESENTATIONS description and critical analysis of existing example of automation in manufacturing or construction
ECONOMIC ANALYSIS economic feasibility, economic analysis methods, evaluation of application alternatives	ON-SITE AUTOMATION IN CONSTRUCTION existing and prototype equipment for high hazard environment and for typical environment, case study (motor grader)
EXPERT SYSTEMS IN CONSTRUCTION concepts, structure and components, application examples	ON-SITE AUTOMATION case study (teleoperators for underwater inspection), final project design session
AUTO. OF CONSTRUCTION MANAGEMENT computer-aided management, resource management, auto. of data acquisition	ON-SITE AUTOMATION case study (concrete placement and finishing), final project design session
CONSTRUCTION AUTOMATION review and analysis of state-of the art in construction automation	ON-SITE AUTOMATION case study (handling of discrete parts), final project design session
CONSTRUCTION AUTOMATION review and analysis of state-of the art in construction automation	STUDENTS' PRESENTATIONS conceptual design, economic analysis of proposed system
STUDENTS' PRESENTATIONS presentation of laboratory project	DISCUSSION discussion of case studies, final projects
STUDENTS' PRESENTATIONS presentation of case studies	REVIEW review, discussion of research topics

Figure 1. Two Courses on Construction Automation Offered Spring Semester, 1990.

Please feel free to add comments to any question. UG = undergraduate level; G = graduate level

1. Does your institution have a formal construction program?
   ( ) yes degrees awarded __________ enrollment ____ ( ) no
2. Is construction equipment management covered? ( ) yes, UG ( ) yes, G ( ) no
3. Are the capabilities of different types of heavy construction equipment (e.g. hoisting and earthmoving equipment) discussed? ( ) yes, UG ( ) yes, G ( ) no
4. Are the capabilities of smaller equipment, power tools, and hand tools discussed?
   ( ) yes, UG ( ) yes, G ( ) no
5. Is hands-on experience in the operation of construction equipment available (for example, through a one-day lab session)? ( ) yes, UG ( ) yes, G ( ) no
6. Is computer simulation of equipment operation available
   ( ) yes, UG ( ) yes, G ( ) no
7. Is the automation (or partial automation) of construction processes covered
   in a course on automation? ( ) yes ( ) no
   in any other course? ( ) yes ( ) no

   If automation is not addressed in the construction curriculum, please indicate reasons:
   no time; curriculum already full ( ) UG ( ) G
   no faculty member available to cover subject ( ) UG ( ) G
   subject not currently relevant to construction education ( ) UG ( ) G
   other (please explain)
8. Is research in construction automation currently carried out at your institution?
   ( ) yes ( ) no
9. Is hands-on experience with automated equipment a desirable component of
   research in construction automation? ( ) yes ( ) no
   teaching in construction automation? ( ) yes ( ) no
10. Please indicate which of the following topics is covered in your institution's construction curriculum. Whether or not the topic is covered, please indicate your assessment of its relative importance in a construction program by circling the appropriate number.
    (not important) 0 1 2 3 4 5 (very important)

scheduling software	UG	G	no	0	1	2	3	4	5
estimating software	UG	G	no	0	1	2	3	4	5
simulation software	UG	G	no	0	1	2	3	4	5
expert systems	UG	G	no	0	1	2	3	4	5
automated data acquisition	UG	G	no	0	1	2	3	4	5
non-destructive evaluation	UG	G	no	0	1	2	3	4	5
remotely operated vehicles	UG	G	no	0	1	2	3	4	5
prefabrication	UG	G	no	0	1	2	3	4	5
human factors	UG	G	no	0	1	2	3	4	5
partially automated construction equipment	UG	G	no	0	1	2	3	4	5
sensors, actuators, controllers	UG	G	no	0	1	2	3	4	5
kinematics of robotic manipulators	UG	G	no	0	1	2	3	4	5
programming of robotic manipulators	UG	G	no	0	1	2	3	4	5
end effectors for robots	UG	G	no	0	1	2	3	4	5
capabilities of construction equipment	UG	G	no	0	1	2	3	4	5
automated construction equipment	UG	G	no	0	1	2	3	4	5
economic evaluation of construction equipment	UG	G	no	0	1	2	3	4	5
automated construction equipment	UG	G	no	0	1	2	3	4	5
design and modification of construction equipment	UG	G	no	0	1	2	3	4	5
automated construction equipment	UG	G	no	0	1	2	3	4	5
operation of construction equipment	UG	G	no	0	1	2	3	4	5
automated construction equipment	UG	G	no	0	1	2	3	4	5

Thank you for completing this survey. To receive the results, attach a business card below.

Figure 2. Curriculum Development in Construction Automation: A Survey.