Embedded Control -A New Key Technology and its Possible Effects on Industrial Engineering Curricula

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Technological advances have always affected manufacturing, trade, and even national economies. In today's rapidly changing world, industrial engineering must keep a sharp eye on such new technologies. Computer technologies double their performance in about every 12 to 18 months. Accordingly, IE curricula must be reviewed and updated on an almost continuous basis. Such rapid and sustained change places unprecedented demands on curricula development and management. The new challenges being faced include the anticipation of new key technologies for timely preparation of new curricula, determination of the relationship of new technologies to other components of the curricula, faculty development, and course material delivery. At the University of Florida's Industrial Research Laboratory, we have invested several years of work in embedded controls and their applications to autonomous intelligent systems. Through our extensive research, we are convinced that embedded control is a new technology that will have profound effects on the field of industrial engineering. This paper discusses issues related to the emergence of embedded control technologies.

In order to better understand the profound effect of new technologies on industrial engineering and industrial engineering curricula, we must first adopt working definition for industrial engineering: the field of engineering that is concerned with the efficiency, productivity, flexibility, robustness, or in short, the competitiveness of industry. Over the past decade, computer technologies have had the most significant influence over the competitiveness of industry. Although the IE profession has focused more on improving competitiveness through operational methods, the accelerated growth in technologies may soon make it more appropriate for IE to be a technology-driven profession. The introduction of these new technologies has provided many opportunities for a new breed of uniquely qualified IEs.

The influence of computer technologies is not a new phenomenon in IE: Consider the period from the 1960's to the 1980's. It is interesting to observe that the use of computers not only facilitated the solution of analytical models in this era, but also affected the type of analytical models themselves, and solution approaches in a very profound manner. The mainframes were the workhorses for the pre-1980's, mostly running in a *batch processing* mode. (A program was submitted to the computer as one of many jobs.) This "batch job" paradigm is still visible in the models and methods of IE, and, consequently, many algorithmic procedures still follow the batch-job paradigm. Under this paradigm, the algorithm has a set of inputs. It then goes through a number of well-defined steps.

Finally, a solution is returned. The IE then interprets the results. Many of today's linear programming formulations, for example, still are solved in this manner. So are many scheduling, network, or optimization problems.

As we study the effect of computer technologies on industrial engineering, we must consider that computer technologies have gone through at least one generation of change, and are about to complete their second. Namely, a network of workstations running in an interactive fashion has become commonplace in the last decade. The UNIX, PC, and Mac workstations provide the workforce with interactive computing through graphical user interfaces. Interactive computing differs from batch processing in a fundamental way. Consider, for example, an area in which the author has extensive industrial consulting experience: schematic capture and board layout design. Designing a layout is essentially a very hard (NP complete) combinatorial optimization problem with many constraints. One tries to make the board as small as possible, with the least number of layers, while assuring the acceptable track, pad, and via sizes, as well as observing the minimal clearances between such primitives. Moreover, the components must be placed on the board following mechanical constraint (such as placing a connector close to the edge) and thermal considerations. There are aspects, such as making the tracks of high speed bus signals of equal length so that the signals arrive at the same time, or shielding from outside noise sources, that are almost an art rather than part of the design problem. Until recently, board design was a slow, cumbersome, and inefficient task. One-step (batch oriented) design algorithms generally did not work very well. Interactive methodologies automated on graphical workstations significantly improved the ordeal of board design. One does not solve a "batch" problem in one monolithic algorithm. A series of design decisions is made -- often, as the design matures, ripping out the old ones and inserting revisions in place. Although, interactive computing has favorably influenced many engineering fields, IE methodologies have for the most part remained algorithmic in the "batch processing" sense. Electronic-spreadsheet-based management techniques augmented with "what-if solvers" are, in our view, signs that IE may be moving to take more advantage of the interactive and incremental solution procedures.

The next major change in computer technologies has to do with the embedded controller. Most microprocessor manufactured today end up as embedded controllers, rather than in general-purpose computers. The evidence that embedded controllers will be a significant player in engineering is visible from the trend in embedded controller sales and use. According to a Motorola study, every household has about half a dozen embedded controller today, a number that is expected to at least double by the end of the decade.

Collectively, embedded controllers in appliances such as cameras, copying machines, and anti-lock breaks substantially influence the use of technologies. Besides the embedded controllers that affect our every day lives, we must also note the controllers that are used in automating various tasks in manufacturing and service industries. Intelligent conveyors, or inspection stations, for example, are built around embedded controllers. An embedded controller has the capability of making a subsystem autonomously intelligent. A system may be viewed as a swarm of loosely connected, cooperating intelligent subsystems. Such systems, at least the artificial ones, constitute a new conceptual and challenging phenomenon. The design and operation of such subsystems require methods considerably different from the traditional approaches. For example, it is quite appropriate to view a job-shop as a collection of intelligent machine tools. Each machine tool may have several controllers that regulate its operation (change spindle speeds or rate of axial immersion, for example), track and compare its performance to historical data it routinely gathers. Through ongoing research at the Machine Tool Research Center at the University of Florida, we have been involved in improving the "intelligence" of such machine tools. In cases where a machine tool regulates its speed based on real-time decisions to eliminate chatter and improve surface finish, the notion of processing time, for example, somewhat looses its appropriateness. Top-down control schemes such as MRP or various scheduling algorithms become inadequate. Moreover, there is some sweet irony in the fact that the scheduling algorithm (most often a heuristic) being developed and downloaded to the machine tools is often solved on computers that may not be as sophisticated as the high-powered embedded controllers running the machine tools. Through artificial intelligence, the individual machine tools not only make local decisions, they can remember and learn from new experiences. In this sense, the machine tools may be viewed as having complex behavior and even display purposeful actions, which cannot be captured by a few parameters such as the processing time and mean time to failure.

In such an environment, the IEs will need to redefine their mission. More emphasis is needed to design the behavior of autonomously intelligent complex subsystems, and in the way these subsystems exchange information and cooperate. The flow of information is also a key element to consider. Perhaps, the days where the IE meticulously dictates the course of operations may be coming to a close. In the near future, we may find ourselves designing intelligent systems and trusting them to do an efficient job when left alone. That is, rather than solving a given problem, the future IE may be charged with designing subsystems that solve their own problems when they arise. This indeed would be a bold conceptual step.

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