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Introduction to the special issue: Intelligent robotic assembly

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''Intelligent robotic assembly'' indicates a complete degree of autonomy and a high adaptability in performing assembly tasks. For instance, a highly flexible and intelligent assembly system appears to be one that can autonomously perform any assembly work in entirely unstructured environments. This system does not require organized, orderly forms of part transport and presentation devices, such as assembly jig and fixture, part feeding devices, tray, magazine, conveyor, etc., but needs only an assembly table where parts to be assembled are stacked up in a cluttered manner.

Without these structurally formed environments how can intelligent assembly make assembly work feasible? The answer can be given clearly only when the assembly system possesses capabilities of perception, reasoning, decision-making and learning, which, in a sense, requires a human-like intelligence. All of these qualities are indispensable for the classification and recognition of parts, environment recognition, part handling, extraction of information on states of part mating, mating sequence generation, extraction of assembly algorithms, etc. . . .

Contrary to an intelligent system, ordinary assembly systems currently being used in industries do strictly require organized forms of part transport and presentation, necessitating all the parts to be precisely positioned in specified locations and orientations. This causes system complexity and integration problems and has been a too stringent requirement to achieve technically. It may also be noted that this methodology is highly application-dependent, indicating that all the devices, equipments and facilities need inevitable changes when products to be assembled vary from one to another.

As market niches gradually require highly customized products, namely customer-driven products, the intelligence issue covering adaptability, flexibility and agility is becoming more important and well recognized as being stringent. As a result of this trend, there will be many more variations in products (geometrical shapes, dimension, optional parts), much smaller batches, tighter delivery schedules and a resulting increase in assembly cost. This situation will require new paradigms of the assembly system, thus demanding not only the harnessing of technology of intelligent machine and part recognition technology, but also intelligent software/information technology to make it adapt to this trend.

One of the strategies to face this evolutionary change is to make the assembly system intelligent while minimizing the system's flexibility: Flexibility demands reduction in productivity and increase in capital investment, while, within the specified degree of flexibility, system intelligence increases functional versatility, adaptability and autonomy of the system due to its inherent capability of perception, information organization, reasoning, decision-making and learning. The objective of this special issue is to show how the intelligence concept can be blended with the currently assembly technology so that the system becomes smarter than it used to be. Intelligence is needed in most steps of assembly work: Assembly stages are typically composed of 1) product design (DFA); 2) Assembly sequence planning; 3) Assembly task planning; 4) Assembly execution; 5) Assembly inspection. Product design, assembly sequence generation and task planning all demands human intervention, and utilizes their experiences and heuristics, while at the execution level, the system needs to be equipped with an ability to cope with uncertainty and change in environments.

Smart product design can be achieved with the aid of optimization and intelligent concepts to facilitate assembly task without impairing the function of final products. The examples in this kind can be found in computer-aided redesign algorithms, rule-base design inference and unsupervised learning algorithms for cluster similar conceptual designs. Hsu et al. proposed a computer-aided product redesign by taking robotic assembly constraint into consideration. The system has the capability of decision-making on whether the product of interest needs to be redesigned and then of aiding the designers in search for feasible design alternatives. The tolerance design concept critical to assemblibility is an important part of the product design. Lee and Yi proposed a tool to support such tolerance design with which assemblibility can be assessed under tolerance specifications.

Assembly sequence generation and task planning also need to be based on an optimized, intelligent methodology, since these important work steps significantly affect assembly cost and productivity. Part precedences, tool change, assembly direction, goal positions, and possible part grasping zones, and associated robot motion planning are some of the considerations to be highlighted. For sequence generation, Swaminathan et al. suggest a design of a planner based upon a plan reuse philosophy, i.e. an experience-based planner. This research shows how stored cases of basic assembly configurations can be applied to given assembly problem. Purvis and Pu approached the sequence generation problem by the use of a case-based reasoning system in which past experiences are combined together to solve a new problem. A task planning method is discussed for a special case of assembly of flexible objects by Miura and Ikeuchi. The method employing a vision-guided assembly strategy, analyzes possible states of flexible

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objects based upon the empirical knowledge of the objects. In this method the vision system verifies that each state transition of assembly process meets preplanned conditions at each stage.

At the task execution level the system has to be equipped with such functional capabilities as perception, information organization, decision-making and learning just as a human is. This is because execution necessitates environment modeling, adaptability to changing environment and updating of assembly execution algorithms. Sharma and Srinivasa discuss some of such features fused in the form of visual feedback. This system has an extended feature of previous similar work in that it can learn a calibration-free spatial representation of 3D point targets invariantly to changing camera configurations.

Among all other stages involved with assembly, part mating is the most important final task. Part jamming due to an undesirable contact state (Sathirakul and Sturges) and initial impact (Liao and Leu) are some of the practical significant problems that are frequently encountered during a mating task. This information is also very much useful for building an intelligent robotic assembly system. The last paper of this issue (Onori and Gröndahl) suggests a new approach to the design of a flexible assembly cell which can be effectively used for high-variant and medium volume production systems. This assembly strategy can then be further pushed towards a customer-oriented philosophy which will be the core concept for the next manufacturing generation.

The current level of assembly technology can handle such problems as assembly in highly-structured environments, assembly of relatively simple, rigid parts and assembly in a fixed hardware configuration. However, future directions of assembly are concerned with assembly of micro, fragile, highly complex parts under reconfigurable, unstructured environments. It is hoped that this collection of the papers would handle some of the intelligence issue associated with those assembly directions. I would like to thank all the authors to this special issue for their valuable contributions and Professor J. Rose, the Editor of Robotica, for encouraging the appearance of this special issue. I also acknowledge gratefully the assistance of Kyung Hoon Kim at the Korea Advanced Institute of Science and Technology in communicating with all the authors and reviewers.

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