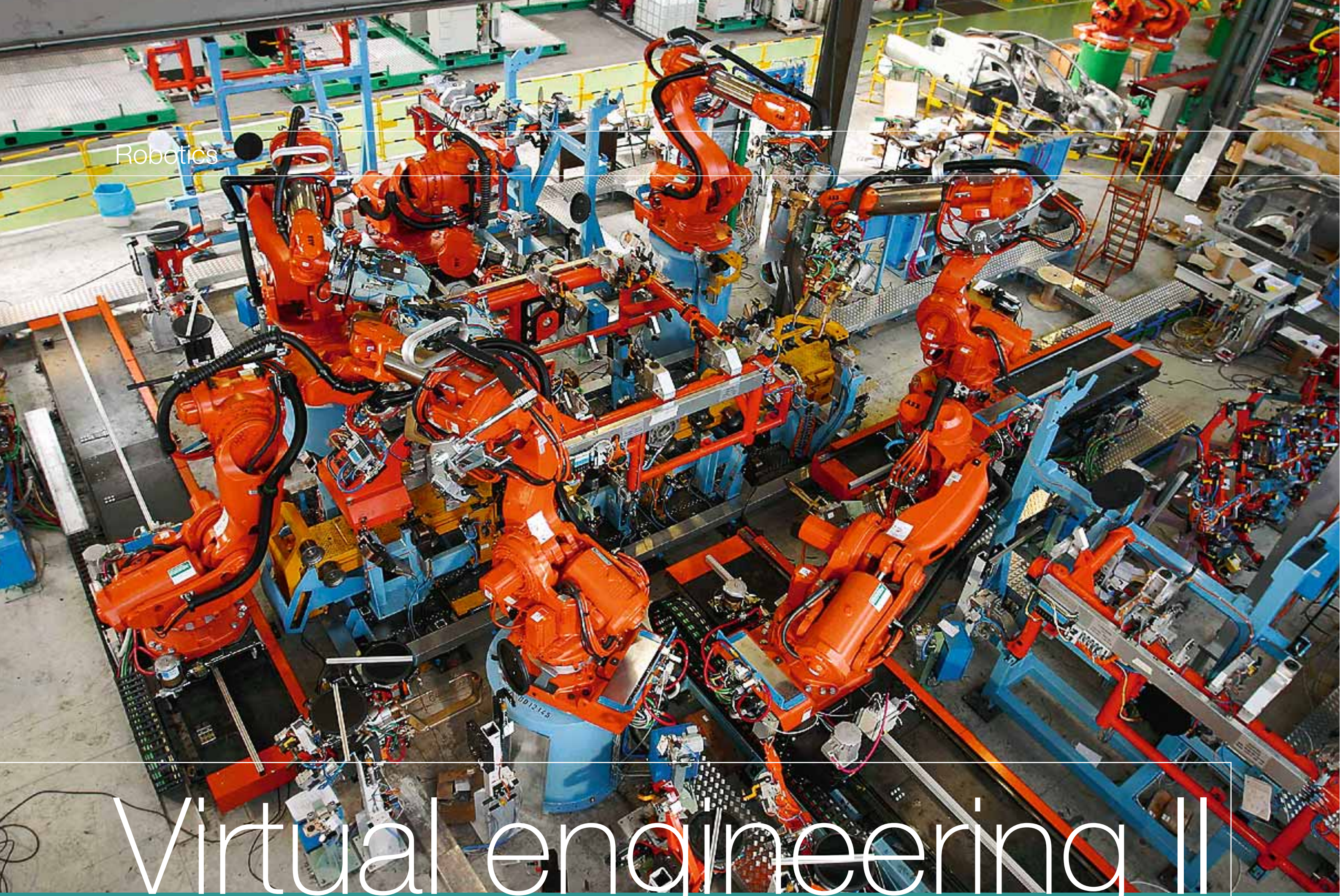

Virtual engineering II

Optimal cell layout for industrial robots improves manufacturing productivity

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Recent ABB research on the optimal cell layout for industrial robots has reduced robot cycle times by as much as 20 percent compared with existing approaches. In automated manufacturing processes such as welding, painting, cutting and material handling, a robot always performs a repetitive sequence of operations along a predefined path. The productivity of a robot can be improved considerably by reducing the cycle time for completing an operation sequence. Robot cycle time depends on many factors, of which the position of the tasks that the robot is to perform is very important. Optimizing the layout of the robot cell can reduce cycle time significantly.

Much research has been carried out in recent years on the issue of cell layout. Basically, the methods proposed can be categorized as follows:

- Adjusting the position of the robot
- Optimizing the position of a task relative to the robot
- Optimizing the position of several tasks relative to the robot
- Redesigning the robot tool
- Optimizing the position of external axes relative to the robot or each other

Each of the above methods has a limited ability to deliver the optimal cell layout, especially when multiple subtasks are involved. Recent ABB research has focused on a three-stage approach to determine the optimal cell layout for a robot to perform multiple tasks in the shortest possible cycle time.

Creating the optimal cell layout

The three stages of ABB's optimal cell layout method are: 1) individual task placement, 2) task sorting and 3) cell optimization 1. During the first two stages alone a near-optimal layout is obtained in a short time.

In stage one, each robot task is placed in a "preferred region" to obtain good initial positioning; then, the most efficient ordering of tasks is obtained by using the switch method; third, the position of each task is adjusted simultaneously by means of the simulated annealing method to arrive at the optimal cell layout. In tests (presented below), the new method has achieved significant and impressive reductions in robot cycle time compared with existing approaches to cell layout optimization.

Individual task placement

Task placement consists of placing each task in a preferred region and rotating it along its own frame to arrive at the best position.

The preferred region is a concentrated area within the robot's reach in which most robot tasks are placed 2. If a robot task is placed in the robot's preferred region, good robot performance and low cycle times can be expected.

Robot tasks are defined by targets. A target can be viewed as an infinitely small object with three coordinates defining its position and three angles defining its orientation in a three-dimensional Cartesian space. Changing the position of a task is the same as changing all targets used to define that task.

Task sorting

When the best position for each individual task has been determined, the question arises of how to sort all the tasks to obtain the best cell layout. Experiments have shown that the best position of a task will remain best when only the first axis of the robot rotates while tending that task. As shown in 3, even if the task position is changed from Position 1 to Position 2, the task is still in the best position for the robot to tend. Task sorting is to find the best space sequence for the tasks under a preset logical visiting sequence. To make rapid task sorting possible, a switched method was designed and incorporated into the solution 4.

Suppose there are M tasks to be sorted. That gives a total of M! possible solutions for task sorting. If M is small, it is possible to search that space which has a dimension of M!. However, if M is large, searching the whole solution space is quite time-consuming. In this case, the sorting method switches to a simplified generic algorithm (GA) method to seek the best sequence of tasks, since GA is an effective optimization method for solving combinatorial optimization problems of large dimensions.

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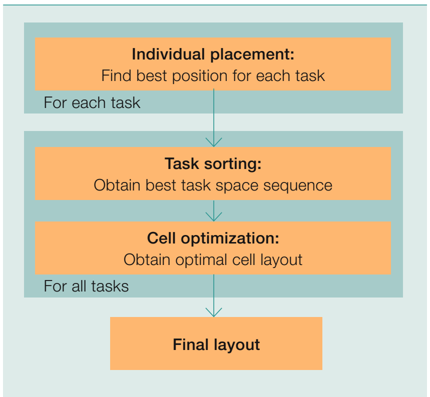
Thus, if the total task number is M < M0 (M0 is a threshold), the best sequence will be searched for throughout the entire search space with dimension M!; while, if M >= M0, the search method switches to the GA-based method to reduce the time spent searching.

Cell optimization

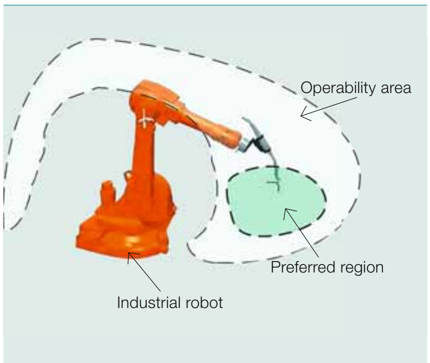
At the cell optimization stage, the simulated annealing (SA) approach is adopted to determine the optimal cell layout for all tasks. After the first two stages of task placement and task sorting, a near-optimal cell layout has already been obtained, which reduces the search space for final cell optimization. SA was selected because it delivers incrementally refined solutions, which provide the user with choice and flexibility. That is, the user can stop the optimization procedure once they are satisfied with the solution provided.

The simulated annealing method has been used to solve various combinatorial optimization problems. One of its advantages is that the optimization process can start with a random layout. The user can specify an initial solution as the starting point to trigger the whole cell optimization process. The process can be stopped during

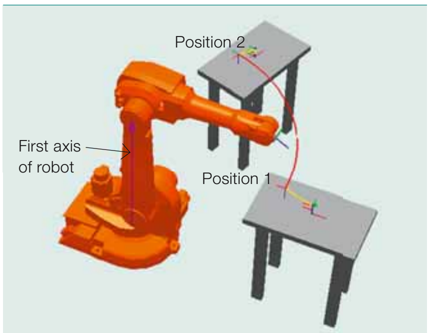
1 Solution map of the optimal cell layout method



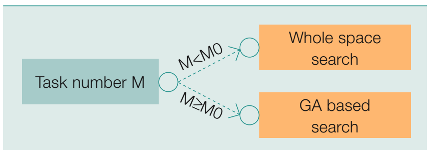
2 Preferred region of the robot



3 Equivalent positions of a task relative to the robot in terms of cycle time

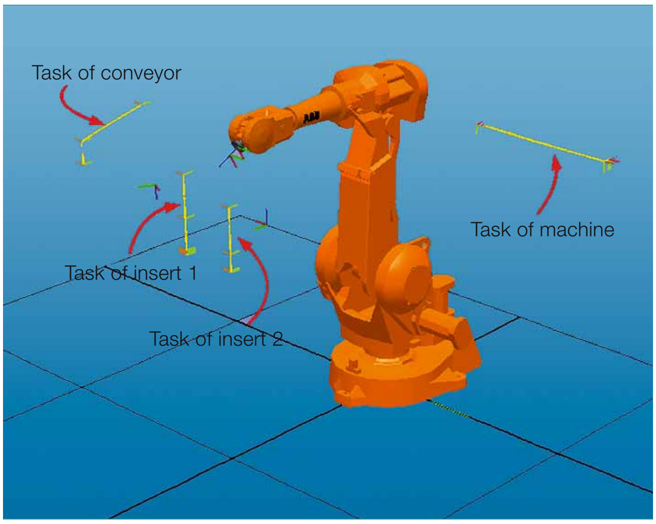


4 Switched method for task sorting

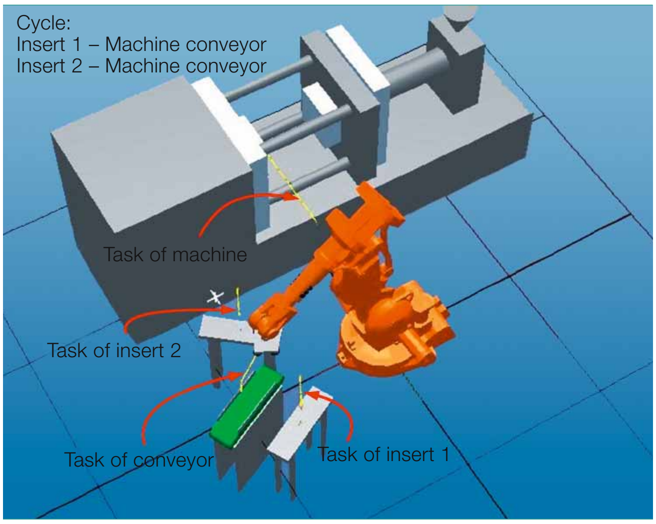


5 Machine tending test case

a Actual cell layout and task positions



b Optimized cell layout and task positions



algorithm execution with an intermediate result, and resumed with the intermediate result as the new starting point. This gives the user flexibility.

Significant reductions in cycle time

Significant reductions in cycle time have been achieved in tests in several applications – two spot-welding cases, one polishing and one machine tending case. Each experiment was performed using RobotStudio, ABB's robot simulation and offline programming software.

Significant reductions in cycle time have been achieved in tests in several applications – spot welding, polishing and machine tending.

In the two spot-welding cases, the robot was required to visit each spot point to perform a welding operation. In spot-welding case 1, the welding points were in alignment; while in spot-welding case 2, the welding path was in an irregular shape. The results were compared with tests using the polynomial fitting method to find the optimal task position. The results of both sets of tests are presented in 6, which shows that the presented method reduces cycle time by 17 and 20 percent in the two spot-welding cases.

The improvement in the polishing case was marginal (1 percent), as the robot task was simple to perform and already in a near-optimal position.

In the machine tending case, the cell consists of a machine for work piece processing, two insert stations and one conveyor. The cycle is composed as: Insert1 > Machine > Conveyor > Insert2 > Machine > Conveyor.

5a shows the cell layout before optimization, and 5b shows the cell layout after optimization. The results in 6 show a large improvement in cycle time of almost 13 percent. The productivity improvement was achieved by the new space sequence of the tasks (stations), and by the positional adjustment of tasks in the optimization procedure.

The experiments confirm that for tasks with complex paths that usually include several targets with different orientations, the new method provides significant benefits; whereas for tasks with simple paths involving a small number of targets with similar orientations, the improvements in cycle time are marginal. This is because robot performance doesn't vary much when the task is repositioned. The experiments also show that for the individual task, reorientation will always influence cycle time more than translation. For multiple tasks, task sorting followed by simultaneous adjustment is an effective way to reduce cycle time.

The success of the research and the size of the cycle-time reductions achieved have resulted in ABB integrating the method into its latest version of Machine Tending PowerPac (MTPP), which was released in September 2008. MTPP is an easy to use robot simulation and offline programming tool that reduces robot simulation times from a typical eight hours to less than 30 minutes, and can be used to create and present robot simulations by a salesperson during a customer visit (see page 86).

6 Test cases and results

Test cases	Existing method (s)	New method (s)	Improvement (%)
Spot welding 1	34.86	28.90	17.1
Spot welding 2	5.56	4.44	20.1
Polishing	30.70	30.40	1.0
Machine tending	21.90	19.0	12.8

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