Hybrid approach for generating laser cutting tool paths

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The objective of the tool path problem is to find a tool path that minimizes the total time required to cut all parts nested on a sheet using a laser. The cutter head needs to cut all elements of all parts and return to its starting location. It is not required that a part needs to be cut in one pass, pre-empting is allowed. The problem is complicated by the existence of precedence constraints coming from inner-outer contour relations and common cuts. Dewil et al.[1] showed that the problem can be modelled as a precedence-constrained GTSP[2] and good results can be obtained through a Tabu search [4] improvement approach. However, when more practical considerations are added to the problem such as piercing and pre-cut costs this approach becomes computationally expensive. Piercing costs are incurred when initiating a cut in a new portion of the plate and a pre-cut has to be placed when a contour is pre-empted. The pre-cut allows the avoidance of a piercing when the laser head returns to finish cutting the contour. Previous research[3] introduced a new construction heuristic to efficiently generate tool paths that minimizes total cutting time taking pre-cuts and piercings into account. One could apply the improvement heuristics developed in [1] to improve the new starting solution. However, because individual elements are considered, a lot of time during optimization is spend looking at possible solutions that do not resemble an optimal tool path. Consider the fact that in a good or even optimal tool path, when the laser head enters a contour for the first time at a certain location, then the laser head will eventually also exit the contour from that same location [1]. As such, the first entry actually fixes relative order and directions of elements [2] in that contour. This information is not considered in the precedence-constrained GTSP approach. Therefore, a different tool path representation is proposed.

In order to facilitate our discussion, a pierce group is defined as an entity that requires at least one piercing. This can be a single contour or a group of contours that are connected to each other by common cuts. If no pre-empting is allowed, a tool path can be represented as a GTSP where every district is a

1. Since pre-empting is allowed, other exits and re-entries can of course occur while cutting the contour

2. In fact two directions are possible, but from an optimization point of view, the direction actually doesn't matter with regards to minimizing total time. And from a technical point of view there is actually a benefit in preferring one direction over the other because a laser head isn't perfectly symmetrical resulting in better quality cuts on a certain side of the laser head.)

pierce group [3]. If on the other hand we assume that only pre-empting is allowed, a pierce group can be seen as a node in a rooted spanning tree. Such a node has child nodes if it is pre-empted to cut other pierce groups. Of course the optimal tool path is not necessarily a minimum spanning tree (MST [5]) between pierce groups as this would entail high pre-cut costs and air movement costs in the case of small contours and large inter contour distances. On the other hand, it also won't necessarily resemble a GTSP between pierce groups as this would entail high air movement costs in the case of large contours and small inter contour distances. These two extremes can be combined by redefining the problem as "Find a partitioning of contours, where a minimum spanning tree is determined between partitions and GTSPs are solved within these partitions in order to minimize the total path travel time".

Besides the advantage that the sub problems are well studied and high quality solutions can be reached in a relatively short amount of time, this representation allows for more meaningful local moves to the incumbent path. The proposed algorithm would function as follows. An initial partitioning of contours is determined. For each of these partitions a (precedence-constrained)-GTSP is solved. Given the GTSP solutions of the partitions, a Minimum Spanning Tree is constructed between the partitions in polynomial time. Every time entry/exit points are altered in common cut pierce groups, a new sub path is determined. At this stage a complete tool path can be constructed, but if the stop criterion is not reached, new partitions can be determined and the process is repeated. If the stop criterion is reached and since precedence constraints are not actively considered in the MST, a repair heuristic can be applied in this stage to construct a feasible tool path. Initial results were of a promising nature, but further research to finish the repartitioning moves and repair heuristic will have to be concluded to confirm these results.

Références

[1] R. Dewil, P. Vansteenwegen, D. Cattrysse *Cutting path optimization using tabu search 739-748*, 2011

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[3] R. Dewil, P. Vansteenwegen, D. Cattrysse *Heuristics for laser cutting tool path generation 210-216*, 2012

[4] F. Glover, M. Laguna *Tabu Search 106*, 1999.

[5] J.B. Kruskal On the shortest spanning subtree of a graph and the traveling salesman problem 28-50, 1956

3. In the case of pierce groups that contain common cuts, the entry node does not necessarily equal the exit node. Therefore the distance matrix should be modified to take this into account