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Manipulating Deformable Linear Objects: Programming using Different Manipulation Skills

Deformable linear objects (DLOs) such as hoses, cables or leaf springs can be found in many industrial products. Automation of production processes involving DLOs is complicated due to the object's deformability and high manufacturing tolerances. Solutions can be found for specific tasks by means of special hardware or complex programming of sensor-based software. However, in general it is difficult to adapt such inflexible solutions to other, even quite similar situations.

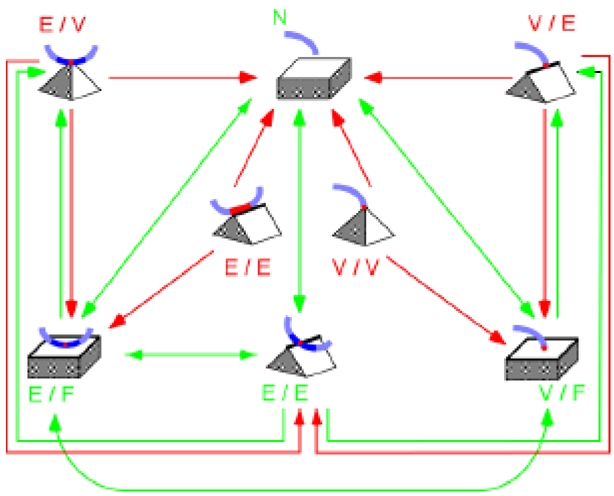

Figure 1: All single contact state transitions between a DLO and its convex polyhedral environment. Initiated transitions (grey); spontaneous transitions (black)[1]

As a remedy, Henrich[1] developed a formal model to describe assembly tasks involving DLOs. The DLO consists of an edge (E) and a free vertex (V). The environment is modeled by convex polyhedrons consisting of vertices (V), edges (E) and faces (F). All contact states between the DLO and obstacle primitives and all possible single contact state transitions are depicted in Figure 1.

For the manipulation of rigid workpieces, Hasegawa[2] introduced the concept of *manipulation skills*: small, robust, sensor-based programs that can perform some common, recurrent, clearly-specified tasks. However, there are no skills to handle deformable objects.

Manipulation Skills

Given an assembly task for automation and its description by contact state transitions, the executing robot system still has to deal with uncertainties, oscillations and precise, intentional deformations of the workpiece. The following three types of manipulation skills have been developed in order to solve these problems in detail:

(1) Given a desired single contact state transition together with a robot trajectory leading to this transition, an appropriate skill should stop the robot motion at the time of transition with the least possible delay. A set of force-based skills for all single contact state transitions with purely translational robot motions was implemented[3].

(2) During assembly processes, undesired DLO oscillations may occur. Since the natural decay time is generally quite long (e.g. >45 sec. for leaf springs), the total assembly time may be reduced using active damping operations. Adjustment motions can be used to stabilize the manipulated DLO after only a few oscillation periods. All parameters can be determined from measured forces and moments[4].

(3) In some situations, objects have to be elastically deformed in order to achieve a desired shape. Given the contact points along with the desired tangent directions and translations for each contact point, an appropriate robot trajectory can be generated using different kinds of Splines for shape approximation[5].

Leaf Spring Assembly

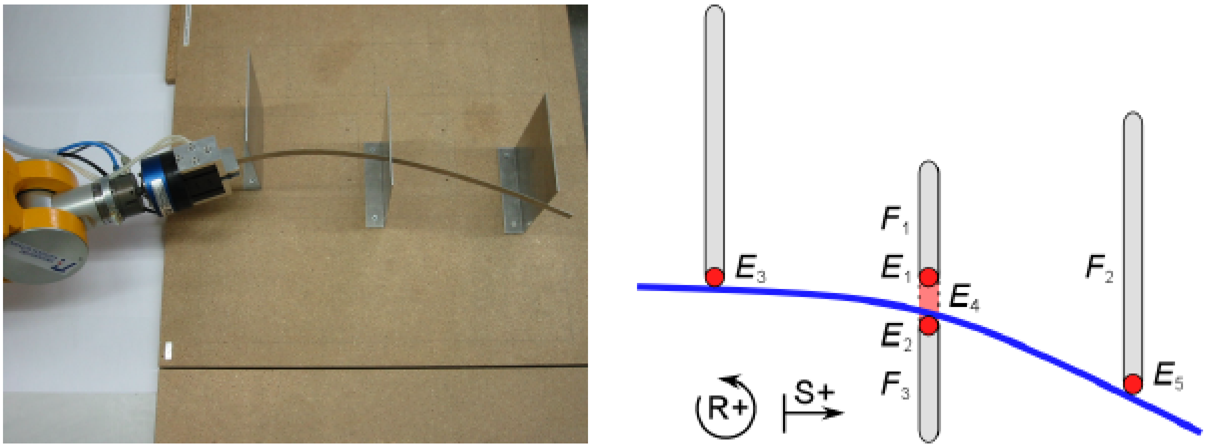

Figure 2: Target situation of leaf spring assembly: Overview (left); Horizontal section with designation of the involved faces and edges. (right)

As an example for the use of manipulation skills, a leaf spring of 50 cm length and 2 cm width should be clamped between three parallel plates of 19 cm height and 15 cm width, situated about 20 cm from one another (Figure 2). The notch in the middle plate is 6 cm high and 1 cm wide. The misalignment of the plates prevents mounting the spring without deformation. In terms of contact states, the goal situation can be described as $E/E_2 \wedge E/E_3 \wedge E/E_4 \wedge E/E_5$, with the designation of edges and faces from Figure 2.

For the implementation, all three types of manipulations skills are needed. Without the intentional deformation skill, the assembly is impossible. This skill is likely to fail without sufficient knowledge of its starting situation, which, due to uncertainties, can only be achieved robustly using contact state transitions. Without active damping of the oscillations after a fast pickup, insertion from above between the first two plates might be unsuccessful. Additionally, oscillations disturb the force-based contact state transitions.

The transition skills require 5 s initialization in order to achieve robust detection with an average delay of 0.5 s. With robot speeds of 5 to 15 mm/s during transitions, 100 mm/s between transitions and pickup speed at 50% of maximum, the total duration of a complete assembly is around 1 minute and 40 seconds. Out of 25 experiments in series, two failed at damping after pickup (8%), eight were successful although the insertion in the notch was not recognized (32%), and the remaining 15 experiments succeeded with no faults (60%).

Conclusion

Programming with manipulation skills is easy, flexible and robust; there are manipulation skills available to perform a desired sensor-supervised contact state transition, skills to achieve a desired object deformation without manually searching for an appropriate robot trajectory, and skills for active damping to reduce long natural oscillation decay times.

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References

1. Henrich, D., and Wörn, H. (Eds.): **Robot manipulation of deformable objects,** Springer-Verlag, London, 2000
2. Hasegawa, T., Suehiro, T., and Takase, K.: *A model-based manipulation system with skill-based execution,* **Transactions on Robotics and Automation 8** (5), p 535, October 1992.
3. Schlechter, A., Henrich, D.: *Manipulating deformable linear objects: characteristics in force signals for detecting contact state transitions,* **Int. Conf. on Advanced Robotics,** Budapest, Hungary, August 2001.
4. Schlechter, A., Henrich, D.: *Manipulating Deformable Linear Objects: Manipulation Skill for Active Damping of Oscillations,* **Int. Conf. on Intelligent Robots and Systems,** Lausanne, Switzerland, October 2002.
5. Schmidt, T. Henrich, D.: *Manipulating deformable linear objects: robot motions in single and multiple contact points,* **Int. Sym. on Assembly and Task Planning,** Fukuoka, Japan, May 2001.