An approach to Short Plan Construction for Deformable Linear Object Manipulation

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1. Introduction

Deformable linear objects (DLO, from here onwards) are found in a large number of industrial processes whose manipulation is a challenge for autonomous robots that intervene in it. This category of objects has special characteristics to take in account, requiring specific solutions to approach to them [1]. Thus, systems built to process the manipulation of such objects have issues in terms of processing times due to the complexity of calculating the possible interactions [2].

One of the main goal of those systems is the generation of a valid plan of actions in order to put it the object in some goal state [3]. There are different approaches to do it: knot theory [4], roadmap based methods [1], learning by observation techniques [5], or finding a minimum path of stable configurations between the starting and goal states [6]. As it is very important to predict the DLO's reactions, it is often necessary to include powerful physics engines to simulate the object's behavior. This kind of engines are very complex to build, and is not always possible to develop one, leaving two alternatives: developing a custom solution, sometimes based approximation rules [7], or domain specific physics calculations [8] [9]. However, the proliferation of free to use powerful 3D simulation engines made this task easier for researchers [10] [11].

In this paper, we present a system capable of generate short plans, composed of up to two steps, able to bring an input DLO to a certain goal configuration. The main contribution of our work is this planning method for DLO simple manipulation with the novel aspect of using a license free simulation engine in order to process the physical interactions of the object in a fast and simple way. By including the simulation engine in our planner, we lighten the computational workload of the plan creation and obtain a fast and simple system, capable of predict accurately DLO's behavior and create plans for their manipulation. The paper is structured as follows: chapter 2 describes in detail our system, and chapter 3 shows the experiment we planned. Finally, we present our conclusions in chapter 4.

2. DLO Simulation and Planning

In this work, we present a system for DLO simulation and manipulation planning. The system receives information related to the initial configuration of a DLO and a goal configuration of the same object, then as a result of its process, it generates to plan containing the necessary steps for transforming the initial configuration into the goal configuration. The input data of the system consists of an ordered list of the three-dimensional coordinates of points. This model helps us in simplifying the way in which the system will manipulate the DLO.

We make use of a physics engine for the simulation tasks. as it saves costly efforts in terms of development time and computing requirements. Currently our system's manipulation planner is able to obtain plans of one or two steps. The whole planning process starts with a pre-processing stage, where the initial and goal DLOs are simulated in the virtual environment. Gripper hands are also input, including a set of available actions to perform on the DLO. Once this setup is ready, the system starts with the planning stage. The planner uses a backwards simulation method where the goal configuration object is

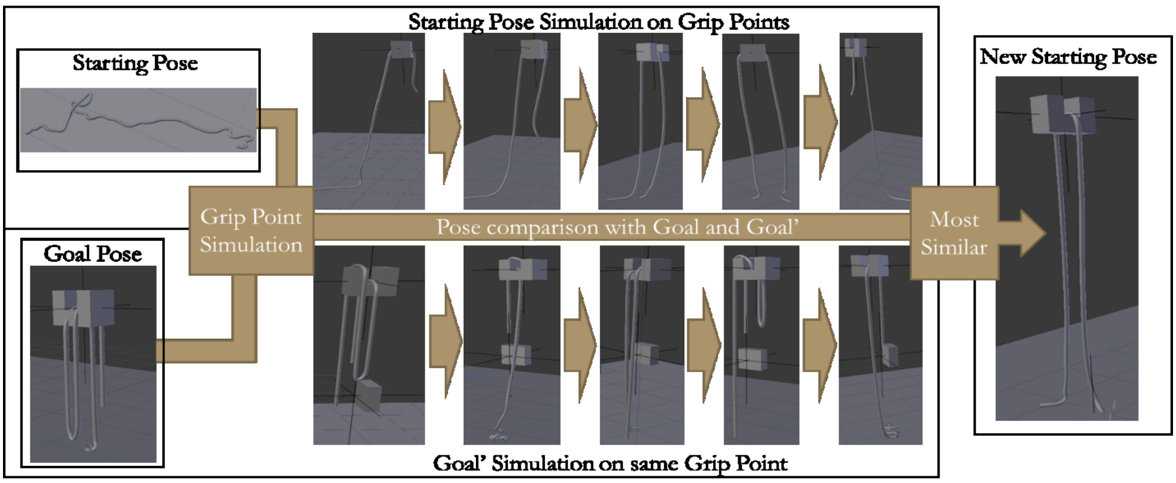

Fig. 1 The system's simulation process: A movement action is performed on each one of the DLO's possible grip points. It also simulates backwards from the goal the same actions. When finished, it selects the most similar outcome to the goal.

manipulated at the same time than the initial one, trying to obtain intermediate points for plans composed up to two steps. The strategy for obtaining plans of more than one step is based on the idea of obtaining intermediate configurations of the original DLO that are similar to the goal. A general depiction of the planner strategy is shown in Figure 1 and follows the next procedure:

- The system begins by performing sequentially each action over each one of the DLO's points.
- Once the action has finished, a modified initial DLO is obtained, and the system checks if it is stable. Unstable configurations are discarded by the planner.
- The system then compares the resulting configuration with the DLO goal configuration, generating a similarity score. The score is stored along with the gripping point, action performed, and action's parameters as comparison data.
- At the same time of the action simulation over each DLO's point, the system also makes a copy of the goal object and the same action is performed on it at the same point, which is also compared with the modified initial DLO. This is done in order to check if the planner needs more actions.
- After storing the comparison data, the initial and goal DLOs are returned to their original configurations and the process is repeated at their next point. Once the system finishes the simulation over all the points, it starts over again with another action.
- Once no more actions are remaining, the planner executes the action from the comparison data with the most similar outcome, creating a new resulting DLO. If the selected action was obtained comparing with the original goal object, the planner considers that the plan is accurate enough with only one step and will finish. If not, more steps are required.
- In case of a two-step plan, the planner repeats the process again with the new initial DLO, but this time the selected action will be the last one.

The system finally generates the plan, containing the details and parameters of each one of the step's actions. Currently the planner is designed to obtain plans up to two steps, but this process will be improved in the future, allowing longer plans for more complex configurations.

3. Experiment

We performed an experiment to test if our planner generates successful plans, suitable for an autonomous robot. The experiment consisted on generating a number of DLO from different photographs of cables, having 90 different combinations of them. We run the planner for each possible combination, and stored the results, divided in three categories depending of their level of similarity to the goal DLO: High similarity, having a similarity degree lesser than 50, Moderate, with similarity degree between 50 and 100 and Low whose similarity degree is greater than 100. Table 1 shows the percentage of results from each category, and an example of one of each one is depicted in Figure 2.

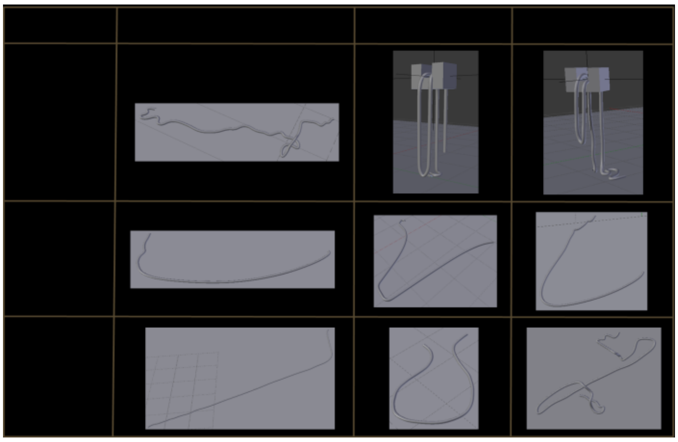

Fig. 2 An example of each category in which we classified the results of our experiment, depending of their similarity degree.

Table 1 Similarity results of the experiment. We classified the resulting DLOs by their similarity degree with the goal DLO.

Similarity	High	Moderate	Low
Resulting DLO	82.98%	8.51%	8.51%

After seeing the results of the experiment, we can confirm that our system is able to generate viable plans to manipulate DLO in any possible configuration: more than the 80% of the resulting DLOs obtained a high degree of similarity with the goal configuration. From the total number of tests, a 72% generated 2-steps plans, and a 28% generated 1-step plans. All of the 1-step plans had high similarity, and from the 2-step plans, a 17.07% were plans whose first step was correct from our observation, failing then in the second, with only a 2.44% from the 2-steps plans failing from the first step.

4. Conclusion

In this paper we presented a system that makes use of a simulation and physics engine to generate plans for DLO manipulation. The system takes advantage of the capabilities of a freely available engine in order to improve its performance and avoid costly development processes, allowing at the same time for interactive simulation. The system currently generates plans of 1 or 2 steps to bring a DLO in a certain given configuration to a goal configuration using a set of gripper hands.

We conducted an experiment in order to test the validity of the planner, generating plans with initial and goal DLOs randomly chosen, obtaining 82.98% valid plans.

In conclusion, we developed a system robust enough to generate effectively short plans for bringing a DLO from a configuration to another, being especially successful in choosing the initial gripping point, and having in account the DLO's physical behavior, two difficult problems present in the current state of the art.

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