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Multi-scale, Reactive Motion Planning with Deformable Linear Objects

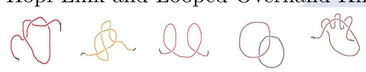
The implemented motion planner is faster and efficient than traditional sampling-based and feedback control methods

Sandhya Prabhakaran, MSc in AI (Supervisor: Dr. Subramanian Ramamoorthy)

Focus Area

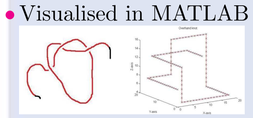
- Importance of Flexible robots - Military, Medical surgery, Nuclear inspection, Aerospace assembly

- Designed a knot tying/untying planner for DLOs to reach desirable goal states from different starts
- Knot types experimented on: Overhand knot, Slip Knot, Untight Knot, Hopf Link and Looped Overhand Knot

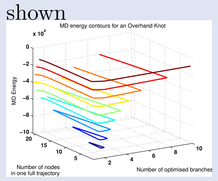


Implementation Method

- DLO parametrised as a Knot
- Basic operations on DLO: Knot-tying and untying
- Visualised in MATLAB as a Polygonal Knot



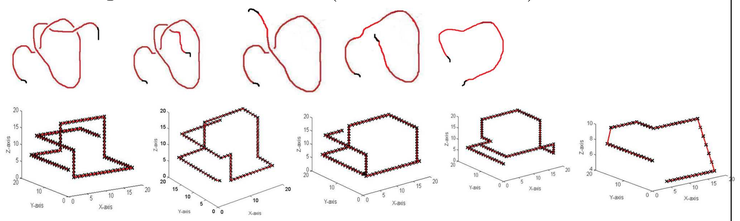
- Creation of Configuration Graphs(CG): entire simulations from knot-to-unknot or unknot-to-knot
- Generalise entire trajectories: using Knot Energy
- Minimum-Distance Energy for Polygonal Knots = $\sum_{1}^{n(n-1)/2} \frac{length(Ei) * length(Ej)}{MinDist(Ei,Ej)^2}$ where n = number of vertices
- This is scale-invariant - depends only on the shape of the Knot
- Group similarly-shaped knot configurations within the CG into similar Energy regions called Knot Islands
- Similar Energy regions are identified using the Energy contours.
- The Minimum Distance Energy contours for an Overhand Knot is shown



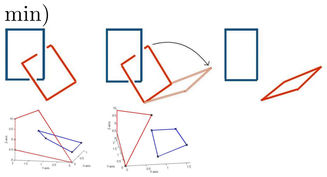
- During Unknot (or Knot) operation, the current Knot MD energy is compared to those of the Islands, the closest island is chosen and within that island, PRM is deployed to get the closest matching Knot configuration.
- Trajectory for an Unknot(Knot) operation is generated by Knot-island hopping rather than node-by-node traversals in the CG. This leads to faster and efficient knotting/unknotting operation

Results

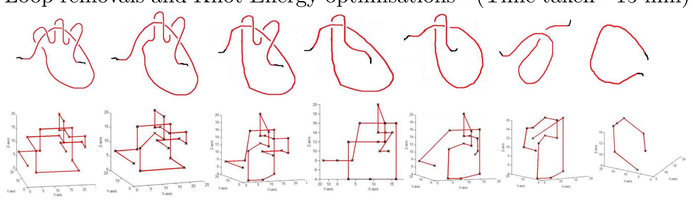
- Unknotting an Overhand Knot - (Time taken - 2 min)



- Unknotting a Hopf Link - Mirror Reflection method - (Time taken - 0.5 min)

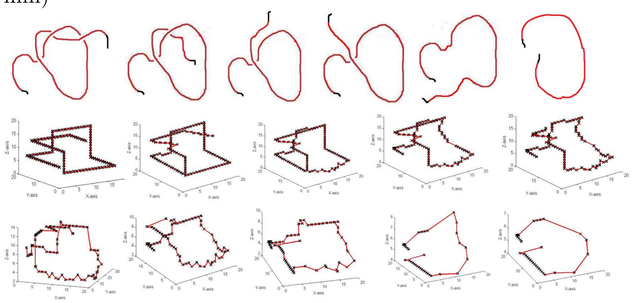


- Unknotting a Complex Looped Overhand Knot through iterations of Loop removals and Knot Energy optimisations - (Time taken - 15 min)



Evaluation of this motion planner against the traditional Probabilistic Roadmap (PRM) planner

- Unknotting an Overhand Knot using PRM planner - (Time taken - 75 min)



- Traditional PRM planner took 75 minutes whereas our knot tying/untying planner took approximately 12 minutes !

Conclusions

Proved our hypothesis of being able to design a robust, multi-scale, reactive knot tying/untying strategy

The knot tying/untying planner is resilient to perturbations

Thus, the multi-scale methods are faster and efficient than traditional methods like Probabilistic Roadmaps and Feedback control.

Also proved that the Minimum Distance Energy is NOT unimodal unlike proved by its inventor in 1995.

All geometrical computations done at 3D level

Future Research

Implement the planner onto Webots / Open Dynamics Engine

Implement more of Special moves on knots so as to interlink between knot types

Extend to cloth dynamics