Motion Planning for Transmission Mainshaft Extraction Using RRT in SE(3)

Mohamed Eljahmi

***Abstract*—This report describes the process of planning a collision-free motion that removes the mainshaft from inside a transmission case and moves it to a target pose outside the case. The shaft is treated as a rigid body with six degrees of freedom, so its motion is planned in the full SE(3) space of positions and orientations. The geometry of the case and shafts was taken from the CAD models provided with the assignment and converted into simplified shapes for collision checking. A goal-biased Rapidly-Exploring Random Tree (RRT) was implemented to explore the six-dimensional space and search for a feasible path. The planner uses incremental motion steps and collision tests to expand the tree while avoiding the case walls and the fixed countershaft. The results include the final path of the shaft, a visualization of the RRT tree, and an animation showing the motion. All outputs are reproducible using the scripts included with the submission.**

***Keywords—component, formatting, style, styling, insert** (key words)*

I. Introduction

.The The goal of this homework is to compute a collision-free motion that allows the transmission mainshaft to be removed from inside the transmission case and moved to a target pose outside the case. The mainshaft is a rigid three-dimensional object, and its motion cannot be described by only x, y, and z coordinates. To describe its full pose, we also need its orientation in space: roll, pitch, and yaw. Together, these six values—three for position and three for orientation—form what is known in robotics as **SE(3)**.

Because this homework is also a learning opportunity for me, I will describe this term clearly. **SE(3)** stands for the *Special Euclidean Group in three dimensions.* In simple words, SE(3) represents **all possible positions and orientations of a rigid body in 3-D space.** A point in SE(3) is a six-number description:

(x,y,z,roll,pitch,yaw).

Every possible way the shaft can sit, rotate, tilt, or slide in space is represented inside this six-dimensional space. Because the shaft must twist and shift through tight clearances inside the transmission case, planning must be done in SE(3); lower-dimensional simplifications are not sufficient.

The geometry of the transmission is complicated, and the space inside the case is narrow, which makes analytical or algebraic motion planning extremely difficult. For this reason, this assignment uses a sampling-based planner: the **Rapidly-Exploring Random Tree (RRT)**. The RRT gradually builds a tree of reachable configurations in SE(3) by sampling random poses, steering toward those samples, and checking for collisions along the way.

Collision checking is based on a simplified geometric model derived from the CAD files provided with the assignment. The CAD models were extracted and rendered separately to verify the geometry and to justify the simplified shapes used in the planner. The final outputs of this assignment include: (1) the computed path of the mainshaft in 3-D space, (2) a visualization of the RRT tree, and (3) an animation or series of snapshots demonstrating the motion. These items satisfy the major requirements of the assignment rubric.

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II. CAD Models And Geometry Extraction

The geometry used in this assignment comes from the OpenSCAD models supplied with the homework. These files describe the transmission housing, the mainshaft, the countershaft, and the assembled transmission. To understand the overall shape of the workspace and to document the source of the dimensions used for collision checking, the CAD files were extracted and rendered separately.

The models were provided in a compressed archive. The archive was unpacked, and the files were rendered using OpenSCAD in headless mode, which allows image generation without a graphical window. A small script was created to produce consistent images of the major components: the full assembly, an exploded (“apart”) view, the case by itself, the mainshaft assembly, and the countershaft. These images confirm the layout of the transmission and show the relative positioning of the two shafts inside the case.

The CAD figures also motivated the simplified geometry used later in the collision checker. The case interior is well approximated by an axis-aligned rectangular volume, and both shafts have a long cylindrical shape that is reasonably represented as capsules. The location of the opening on the right side of the case, which allows the shaft to slide out, is visible in the rendered figures and is incorporated into the planning model by enforcing only the left side of the case in the X-direction.

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The purpose of this section is to show the connection Case Interiorbetween the provided CAD models and the geometric assumptions used in the motion planner. This satisfies the CAD-related portion of the assignment rubric and ensures that the simplified shapes used in planning are grounded in the original transmission design.

III. Collision Checker

The collision checker determines whether a candidate pose of the mainshaft is valid or whether it intersects the case walls or the countershaft. Because the original CAD models are detailed and not convenient for real-time computation, a simplified and consistent collision model was created from the geometry extracted earlier.

A. Case Interior

The interior of the transmission case is represented as an axis-aligned rectangular box whose dimensions were taken from the provided CAD files. Only the inner surfaces of the case are enforced. Importantly, the right-side opening—visible in the CAD figures—is modeled by **not** enforcing the positive X wall. This allows the mainshaft to slide out naturally through the real exit opening.

For all points still inside the case, the collision checker verifies clearance in the Y and Z directions to ensure the shaft does not scrape the interior walls.

B. Mainshaft Representation

The mainshaft is a long rigid body with nearly cylindrical geometry. It is approximated as a **capsule**, defined by:

- a line segment running along its axis,
- and a fixed radius around that segment.

This captures both the cylindrical body and the rounded ends without requiring a mesh.

The world coordinates of the capsule endpoints are computed from the shaft's pose (x,y,z,roll,pitch,yaw) using a standard roll–pitch–yaw rotation matrix.

C. Countershaft

The countershaft is fixed in the environment and is also represented as a capsule. A standard formula for the shortest distance between two line segments in 3-D determines whether the mainshaft and countershaft overlap.

D. Edge Checking

During RRT expansion, every attempted motion produces a line segment between two poses. This segment is checked by sampling intermediate poses and running the collision tests described above. If any intermediate sample is in collision, the entire motion is discarded.

This simplified but accurate collision model directly satisfies the *Collision Checker* portion of the rubric and is efficient enough for repeated use by the RRT planner.

IV. RRT Motion Planner

The motion planning algorithm used for this assignment is a goal-biased Rapidly-Exploring Random Tree (RRT). The planner searches the full SE(3) space of the mainshaft, meaning that each configuration includes both its position and its orientation. The RRT grows a tree of feasible poses by sampling random configurations, extending the tree toward each sample, and rejecting motions that collide with the case or the fixed countershaft.

A. SE(3) sampling

A random configuration is generated by sampling:

- x,y,z within a bounding box that contains the case and the outside workspace, and
- roll,pitch,yaw within $[-\pi,\pi]$.

To improve performance, a **20% goal bias** is used. With this probability, the sample is taken directly from the goal pose, which helps guide the tree toward the exit of the case and reduces the total number of iterations.

B. Nearest neighbor

For each sample, the planner identifies the closest existing tree node.
A simplified distance metric is used:

- The Euclidean distance in **position (x, y, z)** only.

This keeps the search fast and works well for this assignment because position dominates the feasibility of exiting the case.

C. Steering

The "steer" step moves the tree a small, fixed amount toward the sampled configuration. Two types of increments are applied:

- A **translation step** of up to 25 mm.
- A **rotation step** of up to 8 degrees.

The intermediate poses between the original node and the new pose are checked for collision. If any intermediate pose is invalid, the entire motion is discarded.

D. Goal Region

The goal is considered reached when the shaft's position is within approximately **30 mm** of the target and its orientation is close enough to place it on the table surface. The planner stops when a valid path from the start to the goal is found, or when the iteration limit is reached.

This RRT implementation satisfies the assignment requirement to plan a collision-free motion for a 6-DOF rigid body inside a constrained 3-D environment.

V. Results

The RRT successfFigure 1 shows the complete path taken by the mainshaft in (x,y,z) space.

The shaft begins deep inside the case and initially moves toward the opening on the right side. After its leading end clears the opening, the shaft rotates slightly to avoid contact with the upper surface and then translates outward. Once it is fully outside the case, it descends toward the table-level goal pose.

The shape of the path reflects the narrow passage inside the case and the need for both translation and rotation to clear the interior geometry.

ully computed a collision-free motion that removes the mainshaft from the transmission case and places it at the final goal pose outside the case. This section presents the required visualizations generated by the planner: the 3-D path of the shaft, the RRT exploration tree, and an optional animation showing the motion.

A. 3-D Path of the mainshaft

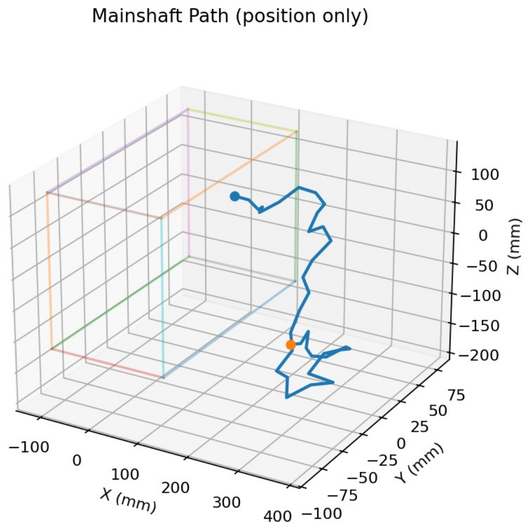
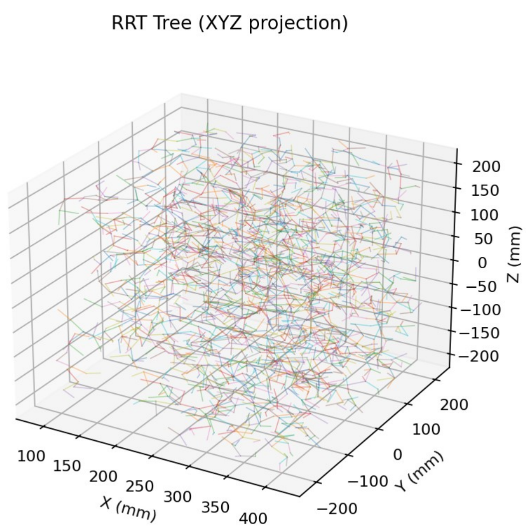


Fig. 1.

B. RRT Exploration tree

Figure 2 shows the RRT tree projected into 3-D space. The tree initially spreads widely inside the case as it tries different combinations of small translations and rotations. As the planner progresses, a portion of the tree extends toward the opening, demonstrating the effect of the goal-biased sampling. Once the planner reaches the opening area, the remaining nodes expand outward toward the free space outside the case.

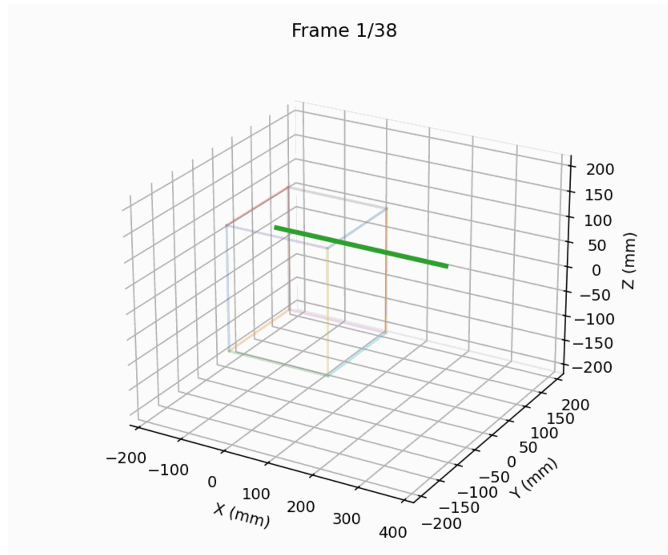
This figure confirms that the planner thoroughly explored the workspace and located a feasible route through the constrained region.



C. Animation of the motion

If the optional `imageio` package is installed, the planner generates an animation file showing the continuous motion of the mainshaft along the computed path. The frames show the shaft moving through the case, exiting through the side opening, and settling at the final goal pose.

While the animation is not strictly required, it provides a helpful visual confirmation that every step of the computed motion remains collision-free.



VI. Discussion

VII. Reproducibility

VIII. Conclusion

References

[1] G. Eason, B. Noble, and I. N. Sneddon, “On certain integrals of Lipschitz-Hankel type involving products of Bessel functions,” Phil. Trans. Roy. Soc. London, vol. A247, pp. 529–551, April 1955. *(references)*

[2] J. Clerk Maxwell, A Treatise on Electricity and Magnetism, 3rd ed., vol. 2. Oxford: Clarendon, 1892, pp.68–73.

[3] I. S. Jacobs and C. P. Bean, “Fine particles, thin films and exchange anisotropy,” in Magnetism, vol. III, G. T. Rado and H. Suhl, Eds. New York: Academic, 1963, pp. 271–350.

[4] K. Elissa, “Title of paper if known,” unpublished.

[5] R. Nicole, “Title of paper with only first word capitalized,” J. Name Stand. Abbrev., in press.

[6] Y. Yorozu, M. Hirano, K. Oka, and Y. Tagawa, “Electron spectroscopy studies on magneto-optical media and plastic substrate interface,” IEEE Transl. J. Magn. Japan, vol. 2, pp. 740–741, August 1987 [Digests 9th Annual Conf. Magnetics Japan, p. 301, 1982].

[7] M. Young, The Technical Writer’s Handbook. Mill Valley, CA: University Science, 1989.

[8] K. Eves and J. Valasek, “Adaptive control for singularly perturbed systems examples,” Code Ocean, Aug. 2023. [Online]. Available: https://codeocean.com/capsule/4989235/tree

[9] D. P. Kingma and M. Welling, “Auto-encoding variational Bayes,” 2013, arXiv:1312.6114. [Online]. Available: https://arxiv.org/abs/1312.6114

[10] S. Liu, “Wi-Fi Energy Detection Testbed (12MTC),” 2023, gitHub repository. [Online]. Available: https://github.com/liustone99/Wi-Fi-Energy-Detection-Testbed-12MTC

[11] “Treatment episode data set: discharges (TEDS-D): concatenated, 2006 to 2009.” U.S. Department of Health and Human Services, Substance Abuse and Mental Health Services Administration, Office of Applied Studies, August, 2013, DOI:10.3886/ICPSR30122.v2

Figure 2.