University of Minnesota

ME 5286 - Robotics

Lab 4: Flashlight Assembly

Azamat Turganbayev (MS Robotics)
Aiden Wang (BS Mechanical Engineering)

Instructors:
Prof. Rachel G. Humann
Prof. Tim Kowalewski

March 31, 2026

Abstract

The main purpose of laboratory 4 was the development and implementation of an automated robotic assembly process using a UR5 manipulator and integrated peripheral systems. The objective was to program the robot to autonomously assemble a flashlight composed of three parts: the head, the battery and the endcap. The system also included a pneumatic clamp with an optical sensor to securely hold the flashlight head during threading operations. In order to successfully assemble the flashlight, accurate localization, trajectory planning and coordinated control of the gripper and clamp were required. Pick-and-place, rotation and torque-controlled tightening custom functions were developed. Overall, the whole system demonstrated the the full assembly sequence within the required time.

Table of Contents

Introduction

The laboratory 4 focuses on the development and implementation of an automated robotic assembly process using a UR5 collaborative robot integrated with peripheral systems. The main objective is to program the UR5 robot using the RoboDK Python API to autonomously assemble a flashlight consisting of three parts: the bead, the battery and the endcap (Fig. 1).

To successfully conduct the experiment, prior knowledge and skills developed in the previous three laboratories are essential. First two laboratory sessions introduced key concepts such as motion in Cartesian and joint spaces, waypoint definition and trajectory execution using Polyscope, RoboDK GUI and Python API programming. [1, 2]. Laboratory 3 introduced gripper control, force application, and interaction with external hardware, which were directly extended in this experiment through the use of a pneumatic chuck, optical sensing, and torque-controlled fastening [3, 4].

Figure 1: Flashlight components used in the assembly process [4]

The main purposes of this laboratory are not only to successfully assemble the flashlight, but also to ensure precision, repeatability, and safe interaction between the robot, sensors, and mechanical fixtures like a pneumatic clamp equipped with an optical sensor, while completing the full assembly process within the specified time constraints: 110 seconds [4].

The discovery question for this laboratory can be put up as: to what extent can a collaborative robotic system, using programmed motion and sensor-integrated feedback, reliably perform a multi-step assembly task with the precision and consistency required for practical industrial applications? In other words, how factors such a s coordinate frame accuracy, motion strategy (joint vs. Cartesian), and interaction with external devices influence the success and robustness of the assembly process.

Methods

Determination of Clamp and Tray Locations

In order to find the location of the clamp and each tray, teach-and-record approach was used within the RoboDK environment. Each relevant position such as tray slots, chuck, pedestal and their approach points were manually defined as target frames with respect to the robot base. For example, each tray location was defined as: *T_SLOT0, T_SLOT1, T_SLOT2, T_SLOT3* in the RoboDK environment. Fig. 2 shows all defined targets in the RoboDK environment.

To ensure safe and repeatable motion, additional intermediate targets were introduced to provide collision-free transitions between key positions. For example, *T_ROT_SAFE* is a beginning target for endcap rotation which ensures safe space for the rotation movement which will be described in details in the next subsection. To identify the clamp location, the *T_HEAD_INS* target was used, which demonstrates the flashlight head seated into the chuck.

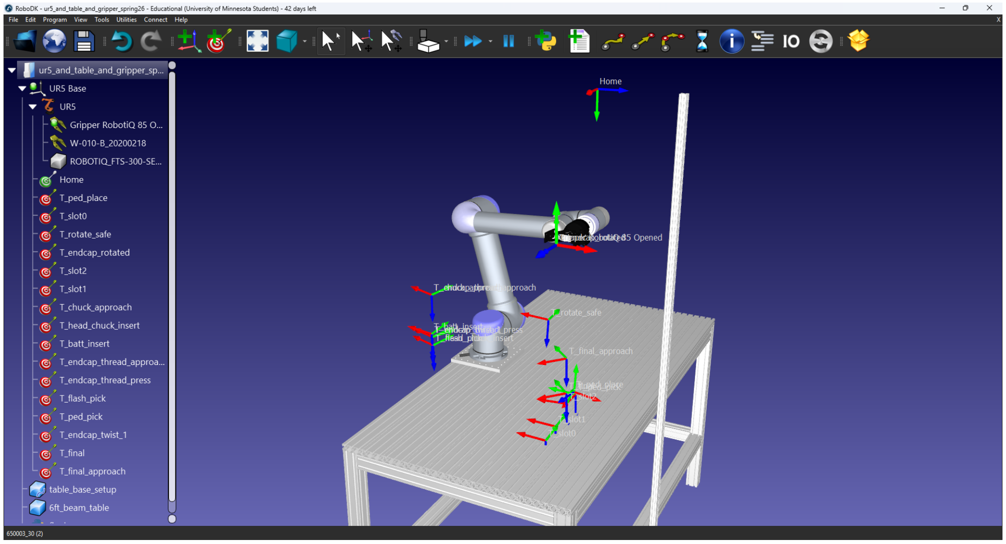

Figure 2: Defined targets in RoboDK environment

Endcap Rotation

The rotation of the endcap was implemented in three stages: endcap placement on pedestal, pre-threading and final tightening. Firstly, the endcap was oriented using predefined targets *T_ROT_SAFE* and *T_ENDCAP_ROT* which ensured safe and proper alignment before insertion. In other words, after picking the endcap from *T_SLOT0*, the robot first moved to *T_ROT_SAFE* ensuring a safe clearance from surrounding objects. Then it moved to *T_ENDCAP_ROT*, where the endcap was properly oriented for placement.

During the second step, after flashlight head with battery inside was inserted and fixed in the clamp, the endcap was picked from the pedestal and placed on the head, the prethread function *prethread_4_strokes()* was applied, where the robot performed repeated tightening motions using the pre defined *T_ENDCAP_TWIST_1* target 4 times. During each iteration, the gripper first securely grasped the endcap, after which the robot executed a tightening motion by moving to the target *T_ENDCAP_TWIST_1*. This motion corresponded to a partial rotation of the endcap relative to the flashlight head. After completing the rotation, the gripper slightly released its grip to allow repositioning, and the robot returned to the initial pose to prepare for the next stroke. The number of iterations was determined empirically to provide sufficient rotation for successful pre-threading before the final torque-controlled tightening step.

Finally, a torque-controlled was executed using a custom instruction *tighten_torque()* provided in the manual [4]. This ensured the endcap was securely fastened without overtightening.

Flashlight Assembly Process

The complete flashlight assembly process was divided into three main stages: endcap preparation, head and battery insertion, and final assembly. Firstly, the robot moved from *HOME* position and picked up the endcap from *T_SLOT0* and placed it onto the pedestal

T_SLOT3. Next, the head was picked from *T_SLOT2* and inserted into the chuck, where it was clamped securely. The battery was then picked from *T_SLOT1* and inserted into the head. Finally, the endcap was picked from the pedestal and aligned with the head. The robot performed pre-threading motions followed by final tightening. After assembly, the completed flashlight was removed from the chuck, placed in the position of slot 2 (*T_FINAL*. It should be noted that due to slight misalignment introduced during the pickup and assembly process the final pose of the assembled flashlight did not exactly match the original textitT_SLOT2 target and could not be used for final placement. As a result, new target *T_FINAL* was introduced for unloading. Finally, after the flashlight was placed the robot returned to *HOME*. The description of the whole assembly process can be found in Appendix A.

Results

The UR5 was able to assemble the flashlight in 1 minute and 39 seconds, which is in the scope of the time dictated in the manual [4]. Within the following timeframe robot picked up each component, positioned them accurately, performed insertion and fastening operations, put full assembly to the final position and returned to home position. The result demonstrates that the programmed sequence was executed efficiently and without interruption. In total 15 targets were predefined to perform the assembly. The Fanuc and Motoman Cartesian coordinates of all 15 targets with their description with respect to the robot's base frame can be found in Appendix B.

Discussion

The accuracy of the Tool Center Point (TCP) plays a crucial role in the success of the assembly process. If the TCP offset is incorrectly defined (closer to or farther from the flange), the robot will misinterpret the true position of the gripper with respect to the parts. As a result, all programmed target positions would effectively be shifted, leading to misalignment during grasping and placement. For example, an underestimated TCP length would cause the robot to stop short of the intended contact point, potentially failing to grasp components. Conversely, an overestimated TCP could result in excessive force application or collisions with the workspace. Similarly, an incorrect estimation of the center of mass or part weight would affect force control and gripping performance. Underestimating the weight may lead to slipping due to not applying sufficient force, while overestimating the weight could result in excessive gripping force, potentially damaging components or causing inefficient motion due to overly conservative handling.

In order to speed up the assembly without increasing both speed and acceleration of the robot, several thing can be done. Firstly, reorganization of the robot's workspace may optimize the assembly process. By placing objects closer to each other the travel distance will be minimized which can significantly reduce the assembly time. This solution is possible for small and flex workspaces. If we talk about massive production, then with the amount of money mentioned in the manual the workspace reorganization will probably be impossible. Secondly, the purchase of higher quality grippers (better gripper fingertips) can potentially reduce the grasping errors which might also lead to the assembly speed up. Finally, optimizing the program by decreasing the number of unnecessary waypoints and organizing more efficient m otion planning will also decrease assembly time. It is not required to use specifically 15 targets for this laboratory, which means, that with proper optimization the number of targets can be reduced.

The most time-consuming steps in assembly were the pre-threading and placement of final assembly. Most of the time on the threading step was spent on realizing the how to implement the threading motion. After finding out the pose of *T_ENDCAP_TWIST_1* target, numerous tests were conducted to figure out the number of iterations required to thread the endcap before applying the *tighten_torque()* function. Regarding the final assembly placement, due to the small misalignment during the threading process the final assembly could not be placed accurately using the existing *T_SLOT2* pose. After many unsuccessful attempts to place the final assembly on the *T_SLOT2*, new target *T_FINAL* was set up and assembly was placed successfully. It can be seen from the Table 1 that the coordinates of *T_SLOT2* *T_FINAL* are similar to each other.

Conclusion

In conclusion, this laboratory demonstrates that UR5 robot can reliably perform a multi-step assembly task. The accurate definition of targets and reference frames was critical to ensue the repeatable positioning since even minor errors in identifying the target poses affected the whole assembly sequence. The choice of motion strategy also played a significant role: Cartesian motions provided safer and more predictable interactions near contact points, while joint motions enabled faster transitions between waypoints. In addition, the integration of the external devices such as clamp improved the robustness of the system by providing the stable platform for flashlight assembly. Overall, the following setup was able to provide the precision and consistency required for practical industrial applications, despite the fact that the performance remained sensitive to calibration and environmental variations.

For future ideas, the whole setup can be scaled to a multi-robot workspace, where several manipulators collaborate to perform parallel or cooperative assembly tasks which might improve the assembly speed up or allow to assemble more complex products. Also, an additional step of testing the flashlight quality and checking on the defective condition can be added since this step was manually performed by students.

References

[1] A. Manicka, A. Johnson, N. Davies, N. Aarsvold, R. Anderson, R. Johnson, J. Knerr, M. Gilbertson, R. Humann, and M. Donath, *Lab 1: Hello Cobot World*, Department of Mechanical Engineering, University of Minnesota, 2026.

[2] P.-H. Cheng, Y. F. Ullah, T. Beckerle, N. Aarsvold, R. Anderson, R. Johnson, J. Knerr, M. Gilbertson, and M. Donath, *Lab 2: Repeatability and Straightness*, Department of Mechanical Engineering, University of Minnesota, 2026.

[3] P.-H. Cheng, A. Johnson, T. Beckerle, N. Davies, N. Aarsvold, and M. Donath, *Lab 3: Gripper Control*, Department of Mechanical Engineering, University of Minnesota, 2026.

[4] A. Manicka, E. Forberger, T. Weber, N. Aarsvold, E. Derse, M. Donath, and R. Humann, *Lab 4: Flashlight Assembly*, Department of Mechanical Engineering, University of Minnesota, 2026.

Appendix

A. Pseudocode for the Flashlight Assembly Process

Flashlight Assembly Process

```
Ensure that robot is in HOME position with open gripper
// Step 1: Endcap preparation
Pick endcap from T_SLOT0
Move to safe rotation position T_ROT_SAFE
Rotate endcap by moving to T_ENDCAP_ROT
Place endcap on pedestal T_SLOT3
// Step 2: Head and battery
Safely leave T_SLOT3 target
Pick head from T_SLOT2
Get to a chuck approach target T_CHUCK_APP
Leave head in the chuck by using the T_HEAD_INS target
Clamp head
Return to T_CHUCK_APP to safely do next step
Move to T_SLOT1 to pick the battery
Get to a chuck approach target T_CHUCK_APP
Insert battery in the head by using the T_BATT_INS target
Return to T_CHUCK_APP to safely do next step
// Step 3: Endcap assembly
Move to T_PED_PICK to Pick endcap from pedestal
Get to a chuck approach target T_CHUCK_APP
Move to T_ENDCAP_THREAD_PRESS target for tightening
for $i = 1$ to 4 do
    Perform partial tightening rotation by moving to T_ENDCAP_TWIST_1
    Slightly release and regrip
    Return to initial position T_ENDCAP_THREAD_PRESS
end for
Perform final torque tightening
// Step 4: Unloading
Close gripper and unclamp chuck
Return to T_CHUCK_APP to safely do next step
Move to final approach target T_FINAL_APP
Move to final target T_FINAL
Open gripper
Return to final approach target T_FINAL_APP to safely do next step
Return to HOME
```

B. Table with all coordinates

Table 1: Target coordinates used for flashlight assembly

#	Target	X (mm)	Y (mm)	Z (mm)	W (deg)	P (deg)	R (deg)
1	HOME	-17.73	-403.36	999.72	-90.00	2.00	-178.00
2	T_SLOT0	-484.06	-458.04	3.09	175.55	-1.96	91.28
3	T_SLOT1	-406.08	-456.73	12.56	179.26	-1.89	92.29
4	T_SLOT2	-328.90	-459.64	57.19	175.82	0.46	98.80
5	T_SLOT3	-260.43	-455.65	66.50	87.71	2.06	-97.78
6	T_ROT_SAFE	-227.41	-344.97	286.66	179.27	-3.39	92.40
7	T_ENDCAP_ROT	-202.98	-356.11	535.47	91.41	-0.50	-92.67
8	T_CHUCK_APP	-332.34	32.32	342.78	176.36	-3.15	75.63
9	T_HEAD_INS	-332.64	32.06	160.98	176.35	-3.12	75.54
10	T_BATT_INS	-333.66	36.25	202.06	174.52	-3.36	85.44
11	T_PED_PICK	-253.37	-458.19	55.22	-179.37	2.28	176.96
12	T_ENDCAP_THREAD_PRESS	-330.93	35.42	190.15	177.21	-1.45	73.20
13	T_ENDCAP_TWIST_1	-331.01	36.44	189.58	179.99	0.42	67.91
14	T_FINAL_APP	-334.21	-456.78	216.63	179.20	1.46	136.92
15	T_FINAL	-334.26	-459.37	96.63	179.20	1.46	136.85

Each target is defined by a 6D pose consisting of position and orientation. The position is given by **X, Y, Z** in millimeters, representing the end-effector location relative to the robot base frame. The orientation is expressed using the **W, P, R** angles in degrees (FANUC/Motoman convention). The short description of each target can be found below.

1. **HOME** - initial and final pose of the robot
2. **T_SLOT0** - endcap pickup pose
3. **T_SLOT1** - battery pickup pose
4. **T_SLOT2** - flashlight head pickup pose
5. **T_SLOT3** - pedestal pose for endcap placement
6. **T_ROT_SAFE** - safe pose to begin endcap rotation
7. **T_ENDCAP_ROT** - endcap rotation
8. **T_CHUCK_APP** - pose to approach chuck
9. **T_HEAD_INS** - pose to insert head into chuck
10. **T_BATT_INS** - pose to insert battery in the head
11. **T_PED_PICK** - pose to pickup the endcap from pedestal
12. **T_ENDCAP_THREAD_PRESS** - pose to put endcap on the head before threading
13. **T_ENDCAP_TWIST_1** - pose for endcap rotation
14. **T_FINAL_APP** - pose for approaching slot 2
15. **T_FINAL** - pose for putting fully assembled flashlight on slot 2