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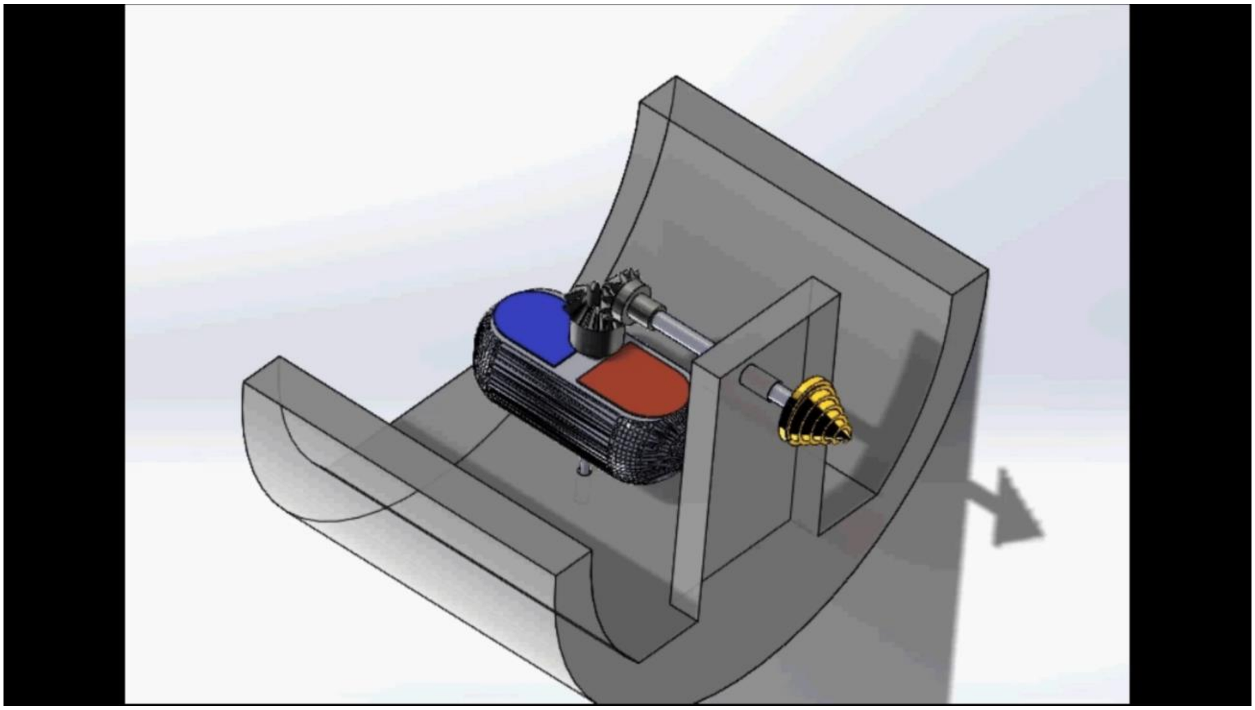
Lab 5

Description of one project idea per lab group member including references (10 points)

- Project Idea 1: Sai
  Idea: Creating a robotic agent for incision
  Aimed at creating a robot to achieve incision using multiple robotic agents. The implementation included the utilization of an anchor and torsional spring to cause incision. The anchored portion would utilize the z axis robot to adhere itself to the base of the petri dish, and the second robot would allow for the rotation of the torsional spring and allow for the cutting motion inside the Petri dish. The idea was developed by taking inspiration from the work in the paper titled " Tetherless Mobile Micro-Surgical Scissors Using Magnetic Actuation" [1]

- Project Idea 2: James
  Thrombosis/blood clot drilling is a fantastic application of using miniature magnetic robots in the human body for minimally invasive surgery. Magnetic drills can be controlled from outside the body and actuated within a blood vessel to a target blood clot which can then be fragmented using the drill to remove the occlusion.
  One design by J. Rahmer et.al [2]utilizes a rotating magnetic field to actuate a magnetic drill. However, a complex field generator is required to create a rotating magnetic field. This is certainly not feasible with the 4-coil EM system. Even if we include the Z-coils to generate a pseudo-rotating field via phase-shifted pulsing, we cannot achieve a high enough frequency to create a roll/drilling motion.
  I am therefore proposing a magnetic drill robot design that utilizes the yaw of the robot to create a roll via a bevel gear. We can comfortably control the x-y position and yaw orientation of the robot using the 4 coils. By constantly spinning the agent in the x-y plane at a blood clot target, we can cause the magnetic drill end-effector to roll about the body axis and drill the clot, as shown in the animation below.



- Project Idea 3: Diana
  More advanced control: implement a “wall detector” that could be applied to navigating through intestines, arteries, bodily organs, etc. And provide haptic feedback to the controller to the surgeon/physician[3]. This would require (1) a way to send vibration to the joystick (2) extremely accurate localization and (3) implementation/an algorithm that considers if the coil is on and if the robot has displaced at all in the direction it is trying to head within. Ie. Let's say the robot is at the far west end of the petri dish and the coil is trying to pull it further west. The algorithm could detect that zero change in location has occurred while the coils are still trying to actuate it in the same direction, and therefore, a vibration would be sent to the joystick to signal to the operator that a “wall” is hit. This could help provide a greater insight to a physician navigating through the human body if the camera has a delay/is inaccurate. Additionally, this could be further expanded by sending different levels of haptic feedback depending on the stiffness of the wall.

Explanation of project selection with rationale (5 points)

The team decided to go with the third project proposal as the student's gained approval for this project from their professor and found novelty in the way this project could be applied outside of the bounds of this lab and into the real world, with some assumptions and limitations, but a general proof of concept. The students agree that this project, navigating around the petri dish, with the addition to the experiment of a maze, with haptic feedback could be translated to a realm without a camera to provide an intuitive sensation to the operator to understand when they are moving in the wrong/right location by vibrating when hitting a wall.

The clinical significance was to have ways in which we could provide feedback for navigational purposes inside the body by knowing the joystick input, location of the robot and the current of the coils. One such use case for this system would be to navigate and palpate the walls of the intestine.

Description of project specifications (5 points)

The project specifications consist of the magnetic system backbone scripts that the students refined in the previous lab with new additions. The students will have the option to use either the dipole, FEA, or gradient pulling to control the robot around the petri dish, showcasing both variability and control. For the haptic feedback the inbuilt MATLAB library for joystick feedback control is being utilized. This would allow for the control of the two motors and varying the force experienced by the user.

Description of experimental plan (5 points)

For the experimental plan, the students intend to showcase the robots and controllers' ability to still operate freely within the petri dish but still give the haptic feedback the students have developed to showcase the localization's ability to determine if a wall is hit in the direction the robot is intended to move within. Additionally, the students plan to provide a qualitative test, one with camera vision and one “blind”. The purpose of this test is to showcase how you can rely on haptic feedback so long that you have a “key” to the maze.

The initial implementation considered using the image recognition of the wall to look at if the robot is hitting the edge of the wall, but the current implementation utilizes if the movement of the robot coordinates are within an expected threshold and the dot product between the joystick input and the robot direction are within an expected threshold. Looking at these two conditions allows us to determine if the robot is colliding with a wall which satisfies the condition of no change in the robot coordinates and application of joystick input. The current implementation was treated as sufficient as it would allow for navigation and object detection without additional image processing.

We are also looking at the norm of the joystick inputs to ensure that there is no input from the joystick. We noticed that when the robot drifts due to various reasons (inertial forces, or the platform having a tilt or due to a fluid flow in the Petri dish), cause the dot product would now change, we would have false detection. Adding the norma of the joystick inputs allowed for reduction in false inputs and account for states where in the robot is drifting due factors other than the application of magnetic force.

For the feedback to the user, we initially planned to have fixed feedback to the joystick when the robot interacts with a wall. Eventually, gradient feedback with respect to time was implemented. The logical thought process was that, as this would allow for the user to differentiate when the robot has just nicked the wall and when the user is applying a consistent force towards the wall.

User study (5 points)

The study group had 4 users and was split into two demographics containing students who have taken the course and those who haven’t. This was to ensure that we would have an unbiased opinion about the haptic feedback and control of the robot when they are explained the general premise and objective.

User No 1(Enrolled in the Course): Feedback and suggestions:

- There are some false positives due the localizer being unable to keep up with the robot, this can be addressed by improving the localizer and having a predictive direction to provide haptic feedback
- The time it takes for the haptic feedback signal to scale could be reduced, as the user felt that the feedback wasn't strong enough
- Suggested the feedback could start at an offset
- Expressed required some time to understand how the system behaves and how the feedback is provided, once they were able to recognize the pattern, they found it easier to navigate and understand the haptic feedback
- Attempted trial to tune the parameters according to account for the grazing of the walls

User No 2(Enrolled in the Course):

- Expressed the same as User 1 to understand how the system would react, to make sense of the system feedback.
- They suggested having a proportional feedback direction further away from the goal and as the robot reaches near the goal, feedback would decrease. This would allow for blindfolded navigation.
- It would be preferred if there were more gradient variations in the feedback to indicate different behavioral conditions experienced in the petri dish. E.g., closer to the goal path but currently encountering a wall.
- Users preferred the robot to not have feedback when it grazes the wall and preferred it to provide constant feedback when its applying pressure on the wall.

User No 3(Not Enrolled in the course):

- After understanding the premise of the system and goal, they required some extra time to navigate the robot around the petri to understand the system behavior.
- Once the system was tuned according to their specifications, they were happy with the feedback provided.

User No 4(Not Enrolled in the course):

- After the necessary acclimatization with the system, they suggested the following changes:
    - Change acceleration rate of the robot to have more finer control
    - The feedback force is optimal
    - Would like it if the robot would give feedback even if its touch the wall but not applying any force

User No 1 Trial 2:

Aim: To navigate the maze, blindfolded with minimal prompts about direction upon collision

- We attempted to have the user blindfolded, and when the user encountered a wall, the person standing next to him would hint at the general direction the robot should be moving towards.
- This showed us the limitations that we would require some kind of audio prompt to allow for the user to navigate a maze blindfolded, this necessary especially when they encounter a wall, as now they don't know which general heading direction they should be going towards. Another idea would be to add more sensors to the agent, such as range sensors to detect proximity to a wall.

Observations and summaries of results (10 points)

From the user study one of the major takeaways would be the fact that majority of the users require some acclimatization time to the system, which is to be expected even if they have taken the course as there is a new feature addition. The feedback response is highly dependent on the user. Some users prefer the robot to react when it grazes the wall, but others find it too much information and something that could be avoided. The tuning of this was achieved by modifying the robot centroid threshold and dot product.

The second take away or limitation of the system that we have noticed is that the angle of incidence makes a large difference, if the robot is perfectly perpendicular or 90 degrees, the feedback loop doesn't get triggered. This can further be improved either by tuning the dot product value, having a predictive direction or having another parameter that compares the angle of incidence and the true heading angle of the robot.

The other limitation that would require debugging would be the goal reached part of the code, which would not function due to the addition of our code. The culprit is due to the fact that we were utilizing a timer function that is messing with break out condition of the while loop.

The users in general were satisfied with the responsiveness of the feedback and how reactive the system was with the maze. There is definite room for improvement but feel this is a very viable method to understand when the system is colliding with an object without using complicated image recognition algorithms.

References:

[1] O. Onaizah and E. Diller, "Tetherless Mobile Micro-Surgical Scissors Using Magnetic Actuation," 2019 International Conference on Robotics and Automation (ICRA), Montreal, QC, Canada, 2019, pp. 894-899, doi: 10.1109/ICRA.2019.8793564.

[2] Rahmer J, Stehning C, Gleich B (2018) Remote magnetic actuation using a clinical scale system. PLoS ONE 13(3): e0193546. https://doi.org/10.1371/journal.pone.0193546

[3] J. A. Griffin, W. Zhu and C. S. Nam, "The Role of Haptic Feedback in Robotic-Assisted Retinal Microsurgery Systems: A Systematic Review," in IEEE Transactions on Haptics, vol. 10, no. 1, pp. 94-105, 1 Jan.-March 2017, doi: 10.1109/TOH.2016.2598341.