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Collision Monitoring for a Mobile Manipulator

Software Development Project
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Introduction

Background

- An existing implementation exists for collision monitoring and avoidance system based on "Biologically-inspired technique" for a fixed manipulator arm [1].

- The implementation consists of 3 different aspects:
    1. Distance monitoring with all the links of a manipulator arm
    2. Potential field computations based on distance from the obstacles
    3. Controller capable of avoiding collisions in real time

- Implementation:
    1. C++
    2. ROS

[1] A. Gomez, S. Parra and B. Penfold, "Implementation of biologically-inspired dynamical systems for movement generation: automatic real-time goal adaptation and obstacle avoidance", 2020.

Objectives/Project Goals

- Understand the existing implementation of collision monitoring for a mobile manipulator.
  - Biologically-inspired dynamical systems for movement generation: automatic real-time goal adaptation and obstacle avoidance, H. Hoffmann et al., 2009 [1].
  - Real-Time Obstacle Avoidance for Manipulators and Mobile Robots, O. Khatib, 1990 [2].

- Check for the scope of improvement in the existing code.

- Extend existing implementation to achieve collision monitoring for a mobile base of a robot.

Requirements

1. Understand the existing implementation of collision monitoring library.
    i. Literature survey.
    ii. Familiarize with C++ and ROS.
    iii. Understand the use cases, mathematics behind the implementation.

2. Check for scope of improvement.
    i. Setup runtime environment of existing library and understand the code implementation.
    ii. Modeling of other shapes.

3. Extension of existing implementation to achieve collision monitoring for a mobile base of a robot.
    i. Setup runtime environment for mobile base.
    ii. Connect existing library with mobile base environment.
    iii. Extend computations in the existing library to:
        1. Perform distance calculations between the base and arm, and other obstacles.
        2. Compute potential field based on the above mentioned distances.
        3. Compute necessary control commands for avoiding collisions.
    iv. Verify the functionality with various test cases.
    v. Check for scope of improvement.

DMP: Dynamic Movement Primitive
CLIK: Closed Loop Inverse Kinematics

Design Details

Collision Monitoring and Avoidance

1. The obstacle avoidance algorithm present in existing library is based on calculating vector fields around obstacles and goals present in the environment.

2. The vector field calculation is a function of distance calculations between colliding objects.

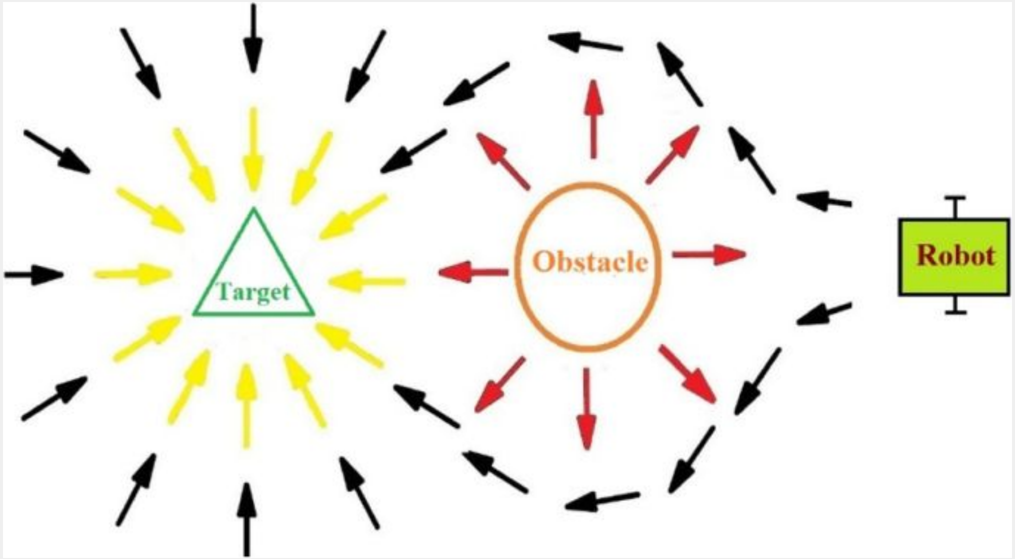


Fig 1: Visualization of vector field, image referenced from [6]

Collision Monitoring and Avoidance: Potential Field

- The potential field is determined by a steering angle that helps to steer away from the obstacles

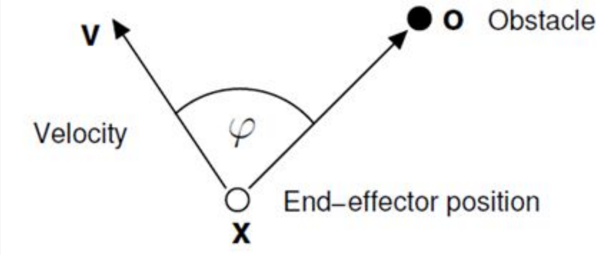


Fig 2: Steering angle calculation

- In [2], the authors show a result of implementation of collision avoidance by vector field generation, as shown below.

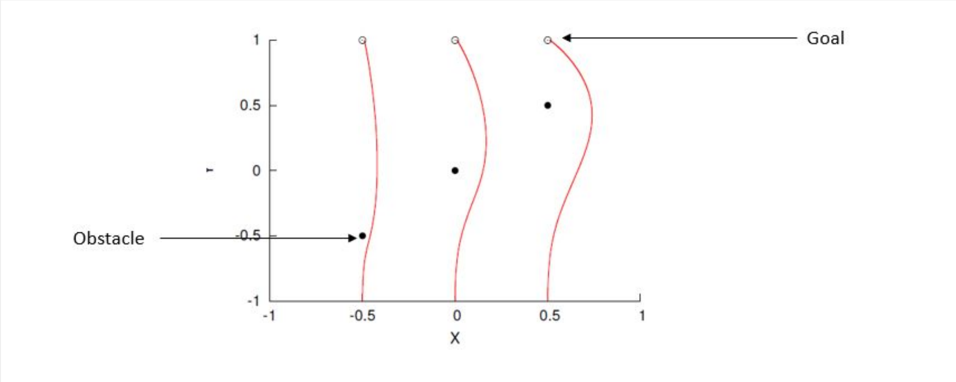


Fig 3: Visualization of vector field and collision avoidance.

Base Obstacle Detection

- Control technique requires information about the obstacles for each time step in order to make robot avoid those while performing the motion.

- To find the distance between colliding objects, they are modelled as different geometric 3D shape primitives.

- This provides simple methods of geometric calculations to calculate distances in real time.

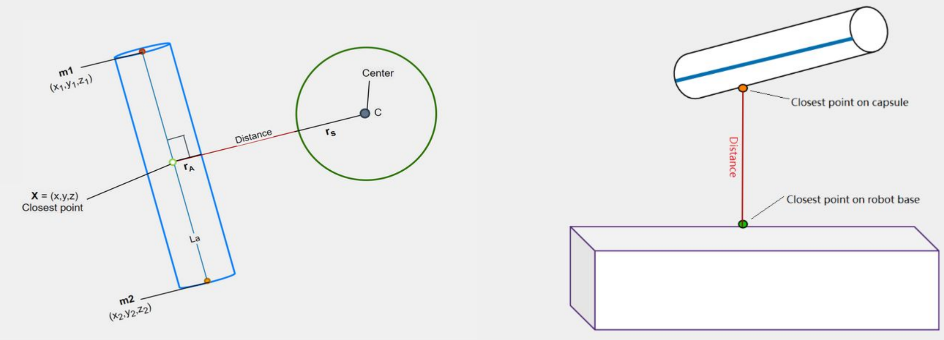


Fig 4: Visualization of Distance calculations between primitives.

Modeling of Robot Base for Distance Calculation

1. The robot base is modelled using AABB [5] geometric primitive. Because:

    a. Can bound almost all the base design for different real world model due to axis aligned 3D spatial spread

    b. Representation is easy, requires only two points (min and max) for representation in algorithm.

    c. Provides cheap distance calculation methods for collision tests

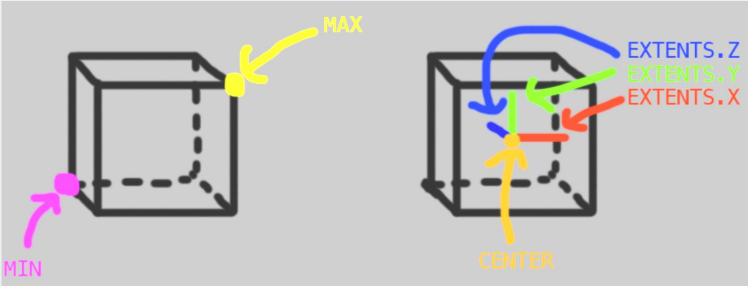


Fig 5: AABB [5] modeling of robot base

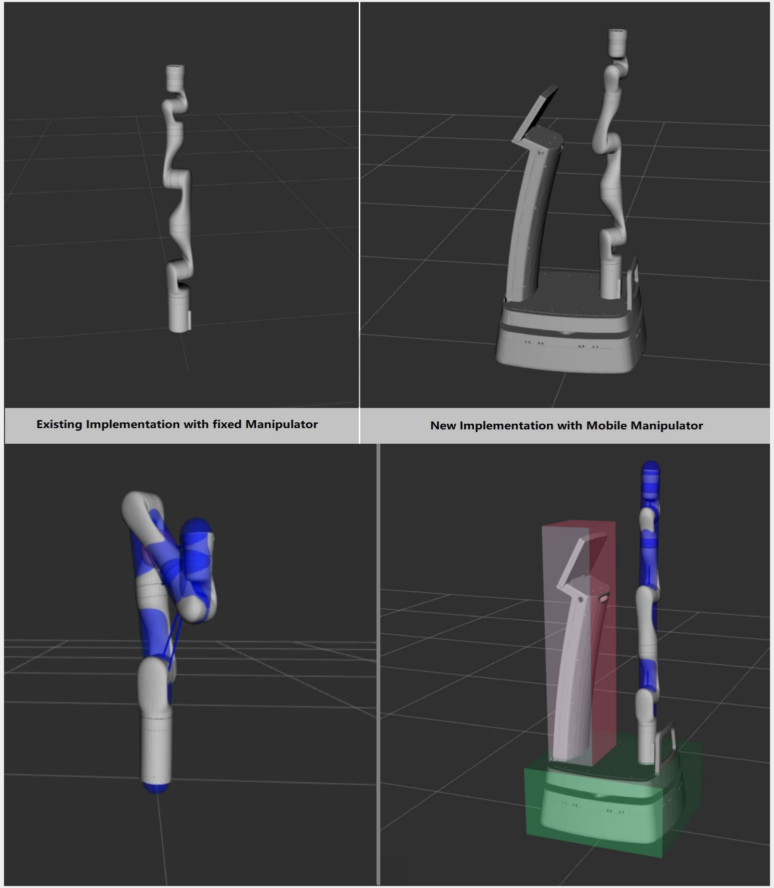


Fig 6: Modeling and visualization of primitives.

Distance Calculation using Box as a Geometric Primitive for Collision Avoidance with Base

Obstacle detection - (Box - Capsule)

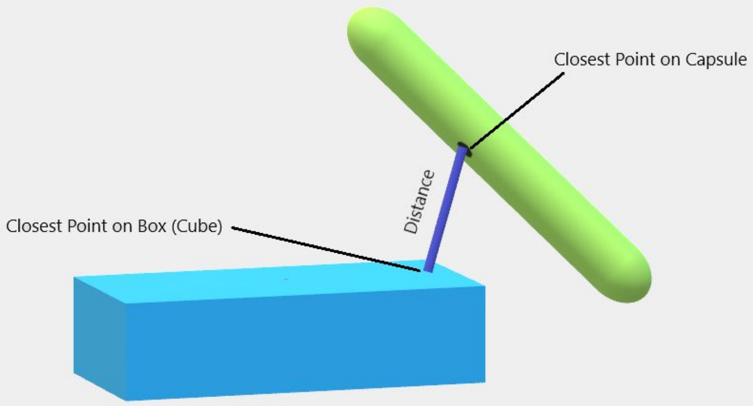


Fig 7: Visualization of Distance calculations between box and capsule.

GJK [4] algorithm for distance calculation with Box

- Gilbert–Johnson–Keerthi distance algorithm is a method of determining the minimum distance between two convex sets.

- To find the distance between colliding objects, they are modelled as different geometric 3D shape primitives.

- This provides simple methods of geometric calculations to calculate distances in real time.

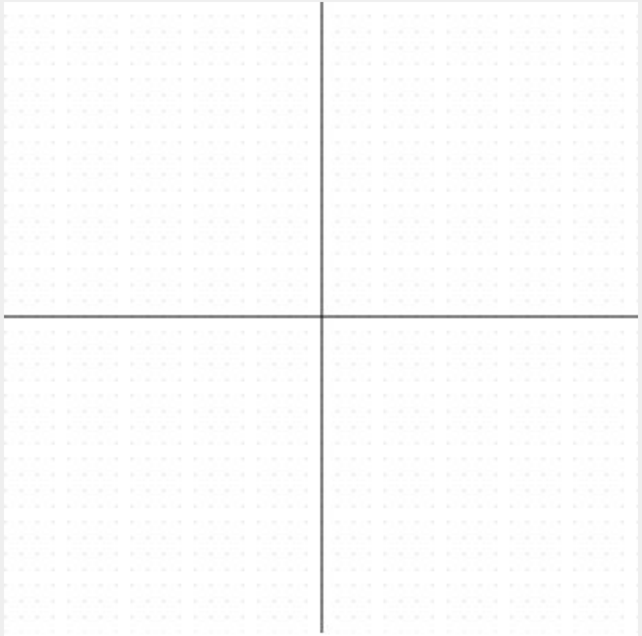
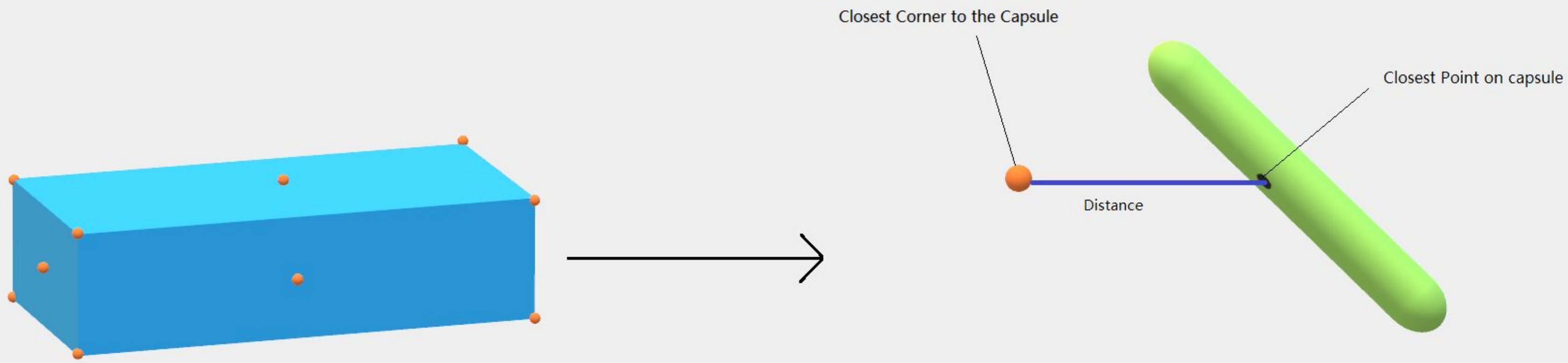
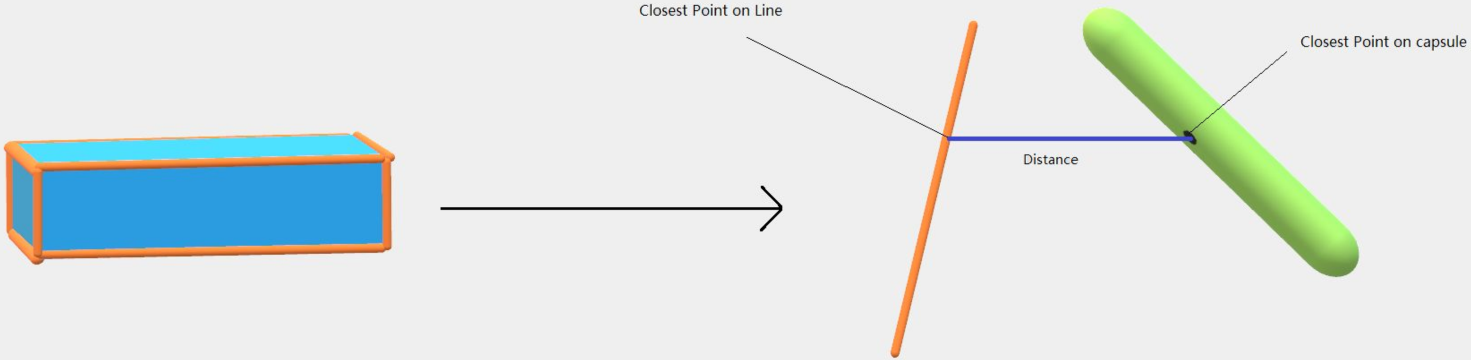


Fig 4: GJK algorithm for collision detection Reference from [https://blog.hamaluik.ca/posts/building-a-collision-engine-part-1-2d-gjk-collision-detection/]

Collision detection algorithm for 3D Box (AABB)



Collision detection algorithm for 3D Box (AABB)



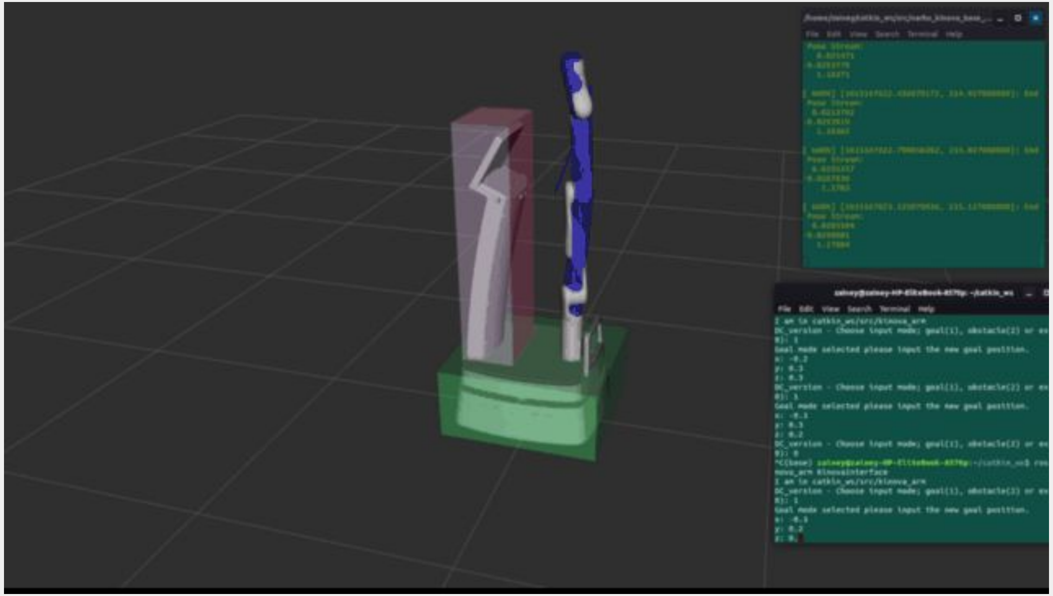
Implementation Details

Implementation Details (Arm - Base)

- Robot base modelling as an obstacle for the arm manipulator

- Control for collision avoidance implementation of manipulator arm with base using vector field approach.

- ROS simulation modelling for demonstration of proof of concept.



Implementation Details (Base - Obstacles)

- Implementation of robot base controller for collision monitoring and avoidance.
- Narko description is used along with kinova arm for modeling and simulating the robot.
- Implementation of PID controller and two wheel differential drive for robot movement.
- Distance calculations between the base and the obstacles in workspace.
- ROS simulation modelling for demonstration of proof of concept.
- Due to imperfect computations, the control algorithm is buggy.

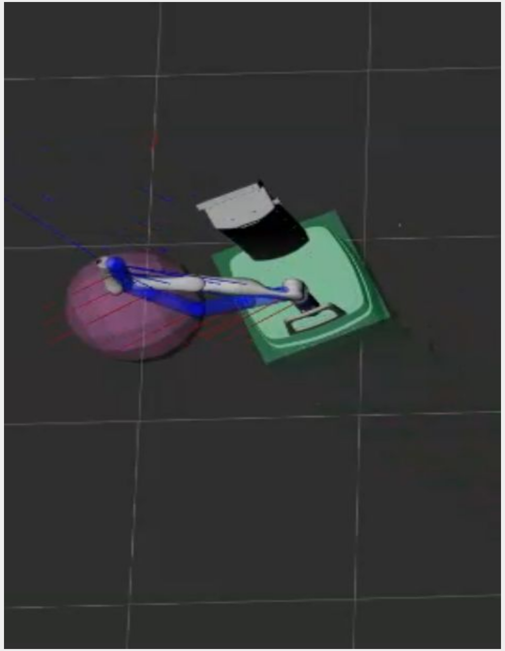
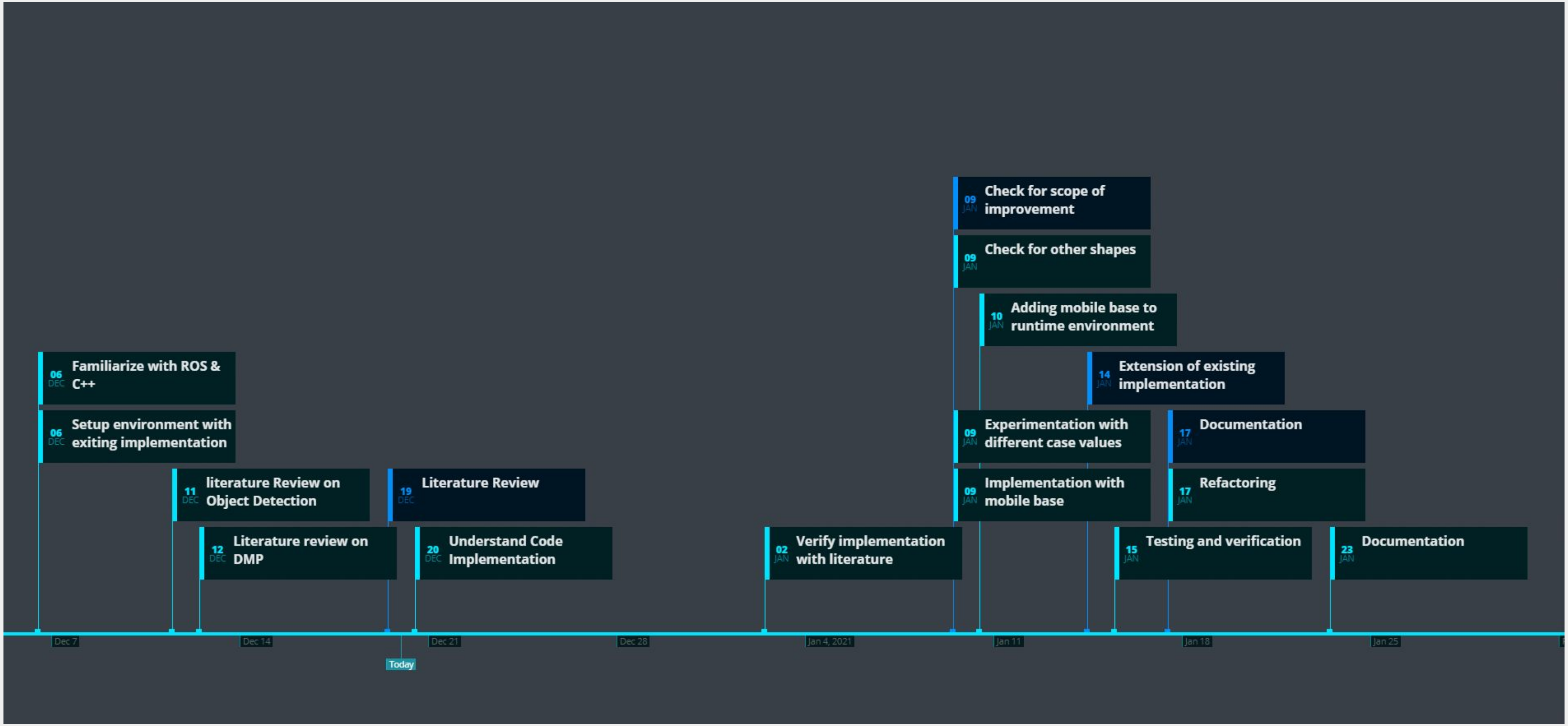


Fig 7: Visualization of wrong movement generation due to calculation errors.

Project Management

Project Management - Milestones and Timeline



Conclusion

Challenges:

- ROS implementation
- Algorithm approach for 3D Box and integration with existing library

Achievements:

- Successful integration of collision monitoring and avoidance of manipulator arm with base
- Extension of collision monitoring library for mobile robots
- Added a 3D box shape to the library for collison monitoring and avoidance

Future Improvements:

- Optimisation of self collision monitoring
- Implementation of mobile base collision with other obstacles in environment

References

[1] A. Gomez, S. Parra and B. Penfold, “Implementation of biologically-inspired dynamical systems for movement generation: automatic real-time goal adaptation and obstacle avoidance”, 2020.

[2] H. Hoffmann, P. Pastor, D. Park and S. Schaal, "Biologically-inspired dynamical systems for movement generation: Automatic real-time goal adaptation and obstacle avoidance," 2009 IEEE International Conference on Robotics and Automation, Kobe, 2009, pp. 2587-2592, doi: 10.1109/ROBOT.2009.5152423.

[3] O. Khatib, “Real-time obstacle avoidance for manipulators and mobile robots. Autonomous robot vehicles”, 1990 Springer-Verlag, Berlin, Heidelberg, 396–404.

[4] E. G. Gilbert, D. W. Johnson and S. S. Keerthi, ”A fast procedure for computing the distance between complex objects in three-dimensional space,” in IEEE Journal on Robotics and Automation, vol. 4, no. 2, pp. 193-203, April 1988, doi: 10.1109/56.2083.

[5] AABB - 3DCollisions - https://gdbooks.gitbooks.io/ 3dcollisions/content/Chapter1/aabb.html, Accessed on 03/07/2021

[6] Rostami, S.M.H., Sangaiah, A.K., Wang, J. et al. Obstacle avoidance of mobile robots using modified artificial potential field algorithm. J Wireless Com Network 2019, 70 (2019). https://doi.org/10.1186/s13638-019-1396-2

Thank You