Problem statement

Given a map of an indoor area, efficiently patrol it, while identifying and pursuing moving objects.

In our project, we will build a node for an autonomous Husarion robot that moves in a 2D environment. The robot will receive an occupancy grid map of the environment and compute patrol paths through the environment representing them as a graph. Once in the environment, the robot will self-localize and patrol the nodes of the graph. When the robot identifies moving objects, it will pursue the target until the environment is clear, then resume its patrol along the graph.

Solution

Our goal will be accomplished by dividing the project into three main sections:

- Map processing
- Local control
- Moving object detection

For map processing, we will create a Generalized Voronoi Diagram from the supplied occupancy grid and produce target poses along the diagram. When in the space, the robot will estimate its own pose and use a local planner (A* or similar algorithm) to follow the patrol poses in the proper order.

For moving object detection, we will use simple background subtraction to find objects moving across the background. We will track moving objects by comparing their size, color and location between frames to try to account for the object moving and rotating. For moving object pursuit, we will use a PID controller to steer the robot until impact with the object, or until the object leaves the area.

Assumptions

Our project uses the Husarion rosbot, which is equipped with an RPLIDAR scanner and an RGBD camera. We assume that moving objects will move away from the robot once they are being actively pursued, that the robot's camera captures video at a high enough FPS to not lose the target between frames, and that the static elements in the environment like furniture will not be changed after the initial map is given to the robot.

Prior Work

Here we review prior work in the tasks of patrol path planning and moving object detection.

Patrol Planning

Patrol Planning is a problem in the subset of path planning where the goal is to produce a path that takes the agent through a space in a complete manner. It is a type of coverage problem. In the state-of-the-art there are two main methods of producing these plans: learning based methods and methods derived from Generalized Voronoi Diagrams (GVD). What follows is a short summary of these methods.

Generalized Voronoi Diagrams are a computational method that mark edges in the map such that the points on those edges are equidistant from obstacles. If the robot were to follow such a path, it would avoid all obstacles while traversing the entire reachable area of the map. Methods in the past decades have focused on the efficient construction of these graphs and optimizing their performance in noisy environments. Tsardoulias et. al (2014) uses the BrushFire pixel expansion technique to generate the graph and then optimizes it using a thinning algorithm. Choset et. al (1998) devises a method for online creation of a Generalized Voronoi Graph (GVG) while the robot moves in the environment. If the robot takes care to stay away from obstacles with a control law, its path can be optimized into a GVG. Hou et. al (2021) uses a technique that could be compared to GVD. Using image processing algorithms, they skeletonize the map and produce nearly noise-free paths even with noisy maps. The downside is that the running time is very long. Overall, the GVD approach is common and has many fast algorithms for its implementation. It's drawback is that it is not very resilient to noise and does not promise a smooth or complete path through the environment.

Learning based methods employ some form of feature extraction on the input occupancy grid map and then set up a topological graph to be optimized. The goal of these maps in addition to the paths created, are to capture the natural structure of built environments in the maps (i.e. each room is a logical cell for the robot to traverse) or even encode semantic information into the cells (i.e. "this room is the kitchen"). Thrun (1998) uses a hybrid method where the input features are derived from a Voronoi graph. In Joo et. al (2010), they identify corner features in the input map and use them to create candidate "doors" that divide the map into cells. These cells are then optimized to find a topological graph using a genetic algorithm. Mozos and Burgard (2006) use a classifier to sort each point of the occupancy grid into a semantic category ("hallway", "room") and then use these to probabilistically divide the map into cells for the final topological map. The main drawback of these methods is their higher computational cost. While robot on-board processing power has increased, training classifiers and running optimization algorithms are better suited for offline pre-processing. While this is not a problem in itself, for our purposes this may be the wrong choice.

Moving Object Detection

Moving object detection (MOD) and tracking is a major area of research in self-driving vehicles in particular. The current state-of-the-art MOD models are modern deep learning systems. For instance, Eslam and El-Sallab proposed the MODETR, which brings the performance benefits of the Transformer architecture to the problem of moving object detection. However, the hardware and latency limitations of our robot makes large, computationally expensive models a poor fit for our application. We can’t rapidly compute object detection, and we need to track moving objects as the robot is pathing toward impact, so we can’t rely on a slow connection to a remote server.

For robots with more limited computational resources, moving object detection is often attempted using background subtraction (Mahamuni et. al.). This technique relies on comparing the current camera image with a stored background image, and targeting the area that is different. This requires our robot to remain stationary and collect information prior to sweeping a room, but it allows us to use a comparatively simple and more efficient algorithm. However, the robot cannot continue to use background subtraction as it moves to intercept the target, because the background changes as the camera moves. To accommodate this, we will store the position of the target object, as well as a snapshot of its associated pixels; we will use this to identify the object in subsequent frames. We will handle rotations and translations of the target by assuming that that the object will only move a little bit between camera frames – if we can identify a slightly translated and rotated object, we should always be able to continue tracking it, as long as our sampling rate is high enough.

References:

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