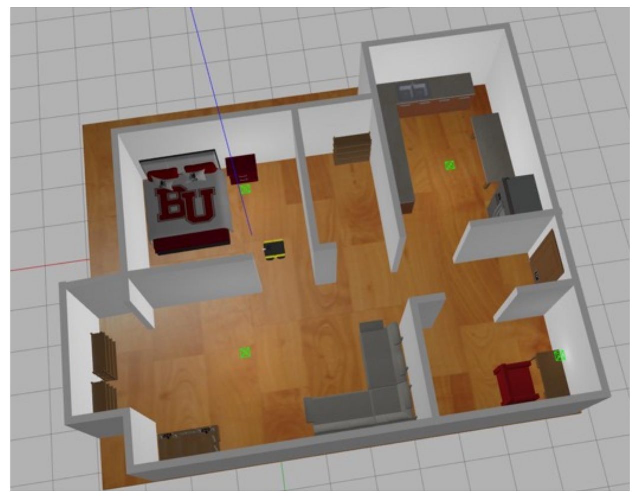
Do More with Less: Single-Model, Multi-Goal Architectures for Resource-Constrained Robots

Zili Wang[1], Drew Threatt, Sean B. Andersson[1,2], and Roberto Tron[1,2]
[1] Division of Systems Engineering, [2] Department of Mechanical Engineering
Boston University, MA 02155

Introduction

Problem Formulation



Given a robot equipped with a laser rangefinder and a limited-footprint object detector in an unknown environment, create an algorithm that minimizes the total path traveled and the number of camera measurements to (a) steer the robot from a random initial position to the exit, while (b) building topological maps.

Previous Work

- Low Resource Robots: small scale and low cost, but limited in sensing and computing resources.
- Semantic Navigation and Mapping: requires high quality sensors and intensive computation.

Our Contribution

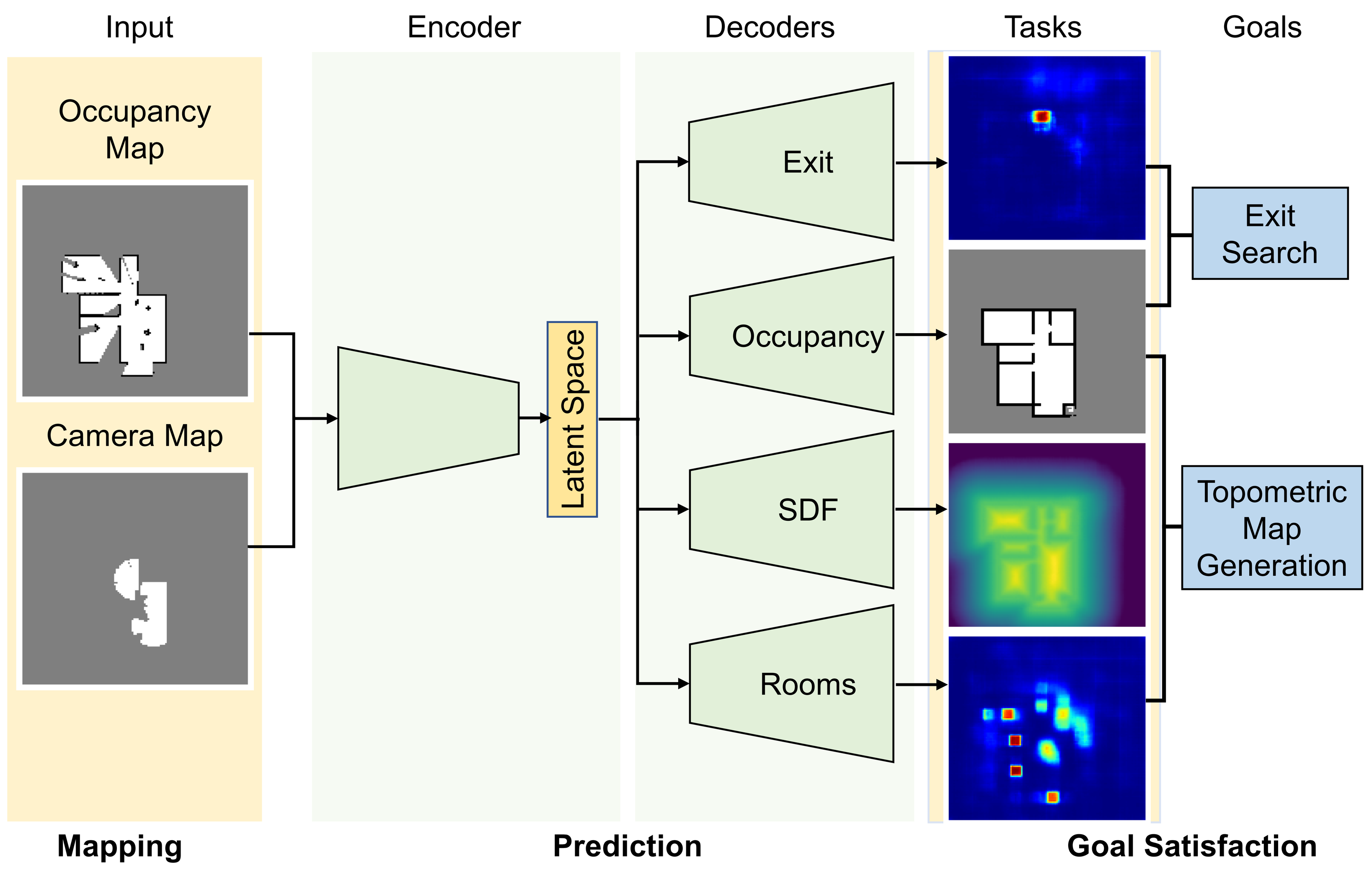
Trained a multi-task U-Net deep network to

+ extract high-level information from low-level measurements, and
+ perform high-level tasks.

Multi-task Model

We use a multi-task U-Net architecture with skip connections.

- U-Net: leverage prior experience on similar environments to extract semantic information directly from low-level measurements.
- Multi-task Learning: give a shared latent space representation that includes geometric and semantic information of the environment.



Model Training

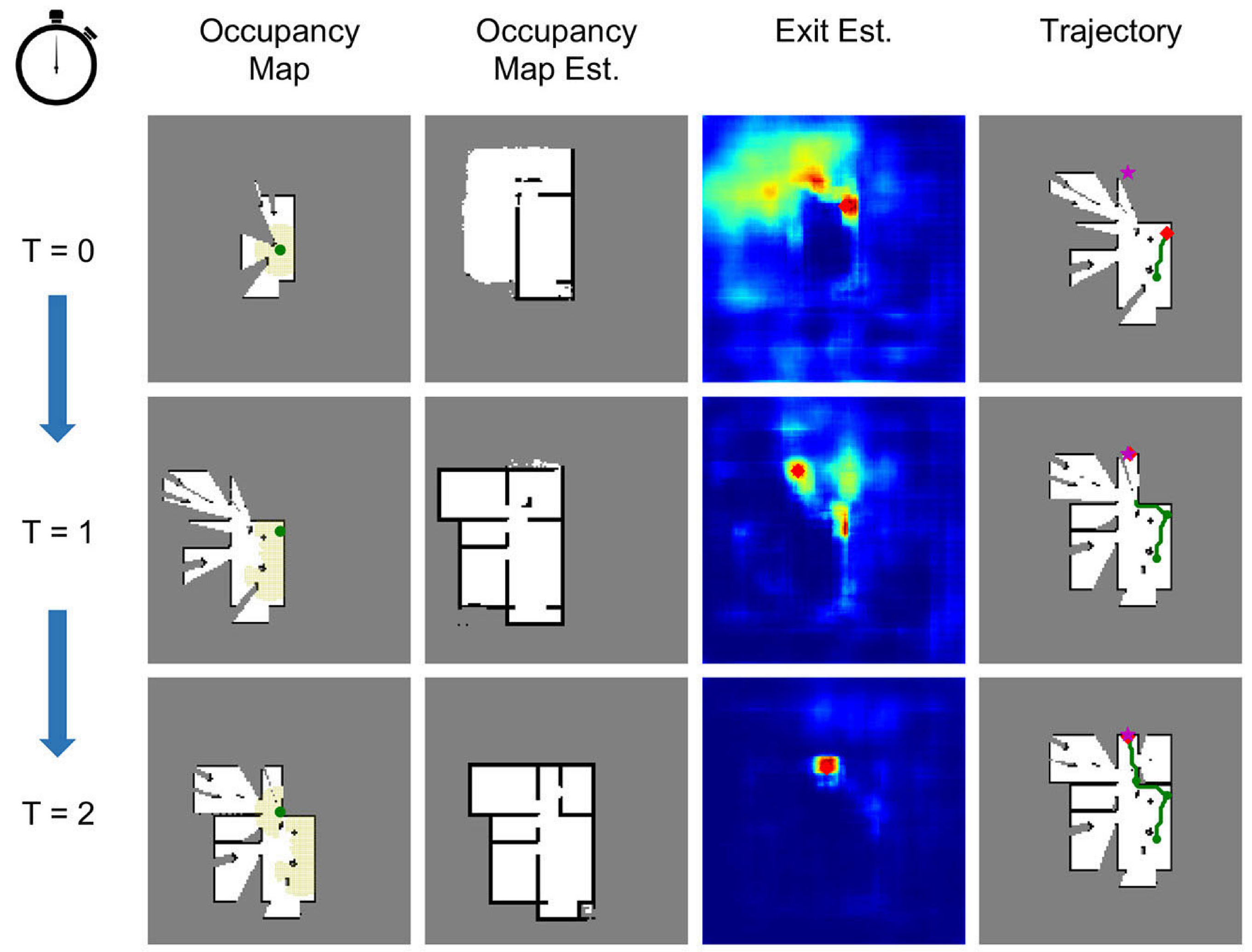
To provide robust training, we use:

- 1k floorplans from the RPLAN dataset, with randomly added small obstacles.
- PseudoSLAM platform (Li et al. IROS 2020) for fast simulation.
- multiple exit search/map completion strategies to collect 100k data samples.

RPLAN dataset, Wu et al. *SIGGRAPH 2019*

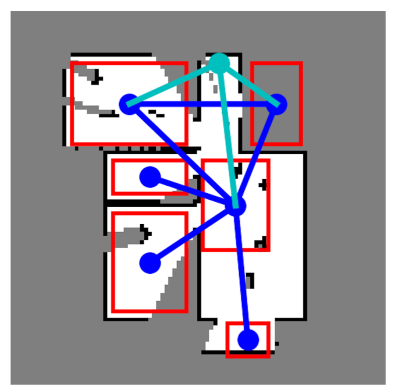
Exit Search

We use the multi-task model to iteratively plan a trajectory to the exit.



- Mapping: accumulate occupancy and camera maps (camera is triggered to detect the exit at the start or when an interim goal is reached).
- Decision: pass local maps to the model, and select interim goal from the exit heatmap.
- Planning: plan a trajectory on the hallucinated occupancy map.

Topometric Map Generation



We use the multi-task model to create topometric maps.

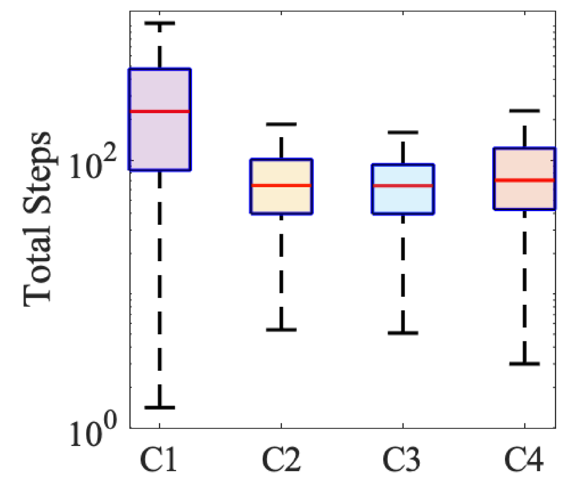
- Room Nodes: room centers are from room centroid estimates; room sizes are from SDF estimates.
- Edges: determined from traversability between two nodes on the occupancy map estimate.

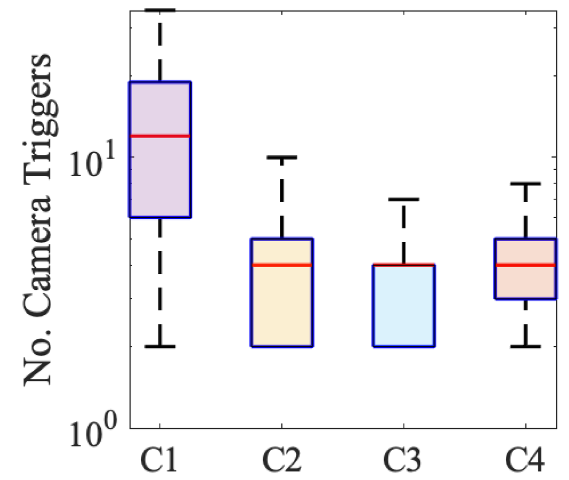
Results

We test our exit search algorithm over 200 trials in 67 new environments.

	(R1) ↓	(R2) ↓
Frontier (C1)	297.7	12.8
Single-task Model (C2)	124.0	5.4
Multi-task Model (C3)	**106.8**	**4.6**
Lightweight Model (C4)	150.1	5.9

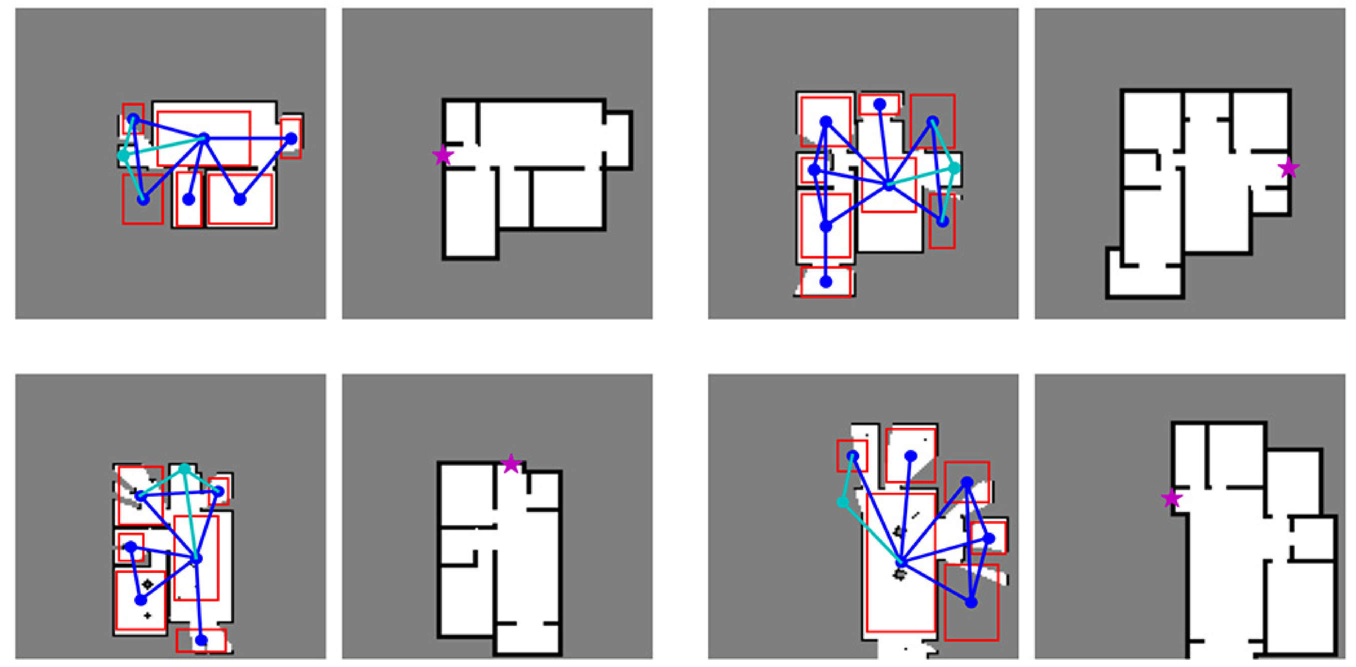
R1: average number of total steps to reach exit.
R2: average number of camera triggers.





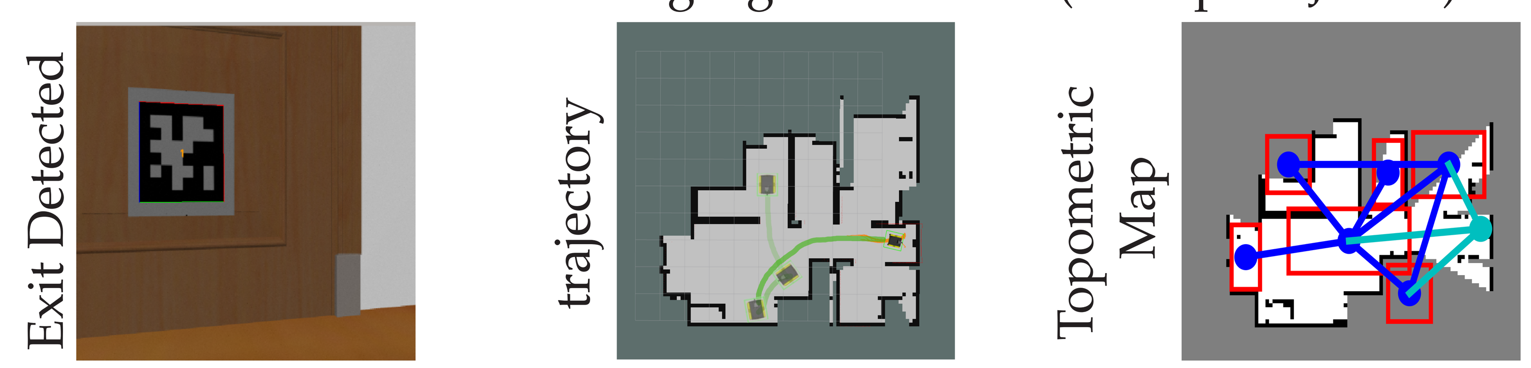
+ Our method is complete and superior to the baseline frontier-based method.
+ Our multi-task architecture yields better performance than single-task model.
– Tradeoff model size vs performance via introducing lightweight MobileNet.

We provide examples of the qualitatively correct topological maps.



Gazebo Simulation

Demonstrations in Gazebo using a ground robot (Clearpath Jackal).



Future Work

- Consider imperfect odometry and sensing.
- Combine with furniture/cluster removal methods.

video