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Towards life-long mapping of dynamic environments using temporal persistence modeling

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Presentation Outline

- Introduction
- Proposed method
    - Temporal Persistence Modeling (TPM)
    - Navigation with life-long TPM maps
- Experimental Assessment
    - TPM map evaluation
    - Navigation with TPM evaluation
- Conclusions

Introduction

- Conventional simultaneous localization and mapping (SLAM) methods can model the explored environment with great accuracy
- Built maps soon get obsolete in highly dynamic environments with moving objects
- Robots are expected to operate alongside humans for extended periods of time with minimal intervention
- Life-long mapping systems aim to solve this problem

Introduction

- Temporal persistence modeling is used to predict the state of each cell of the metric map, based on temporally sparse observations
- Predicted map is used in global path planning to avoid probable obstacles
- Method is evaluated in a simulated, dynamic factory floor

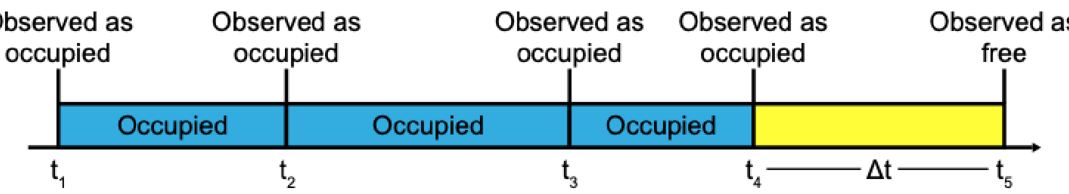
Simulated factory floor

Proposed Method

- Temporal Persistence Modeling:
  - Each cell's occupancy is approached as a failure analysis problem
  - Temporal persistence is defined as the time needed for the state of a map cell to change from "occupied" to "empty"
  - Given the current time t_c and the last time t_l, a cell was observed as occupied, the aim is to calculate the probability P that said cell is still occupied
  - Exponential distributions can model the time elapsed between events, such as temporal persistence, using one rate parameter, λ and $\lambda = 1/\mu$, where μ is the expected value of the distribution

Proposed Method

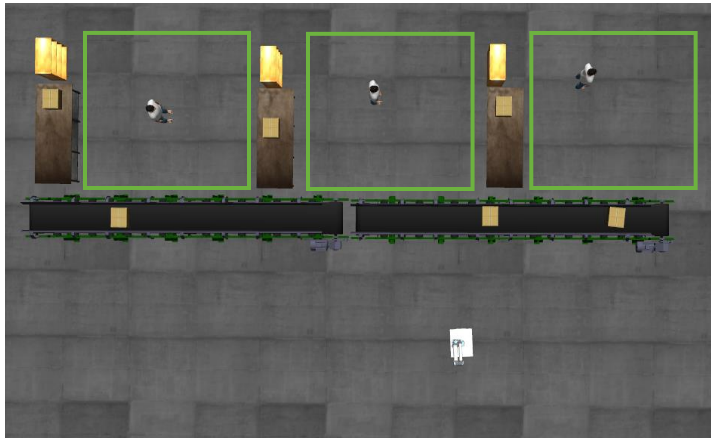
- Temporal Persistence Modeling:
  - Because each cell c cannot always be observed, μ is calculated in a probabilistic manner each time a cell c is observed as free.



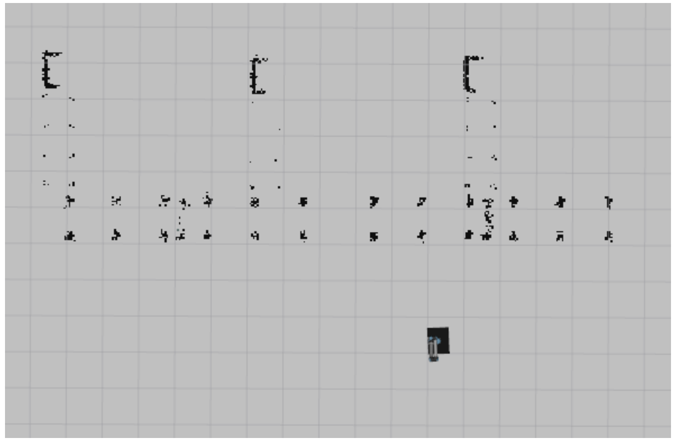
  - After observing a cell as occupied at times t_1, t_2, t_3 and t_4 and as free at t_5, we assume the cell became free somewhere in the middle of ΔT.
  - This leads to fitting a normal distribution over Δt, in order to randomly pick a time, needed for calculating μ
  - Thus, λ can be calculated and then the probability P, that the corresponding cell is occupied

Proposed Method

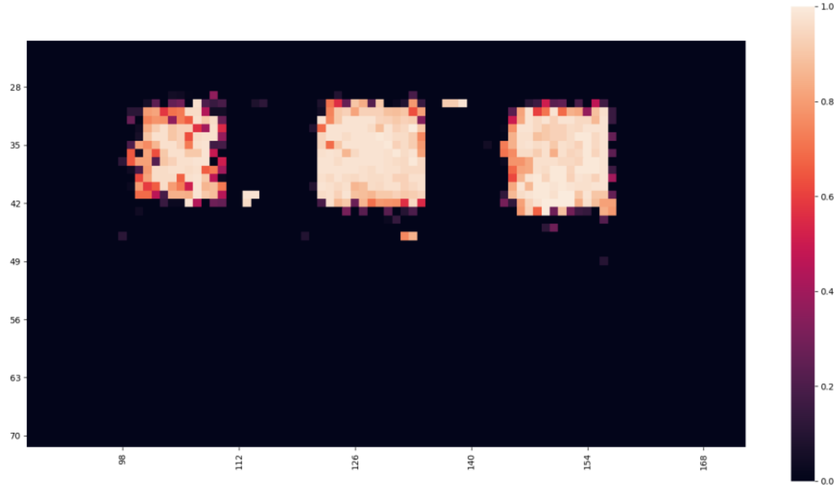
- Temporal Persistence Modeling:



View from a location in the simulated factory floor, where workers move arbitrarily around in their workspaces (marked green)



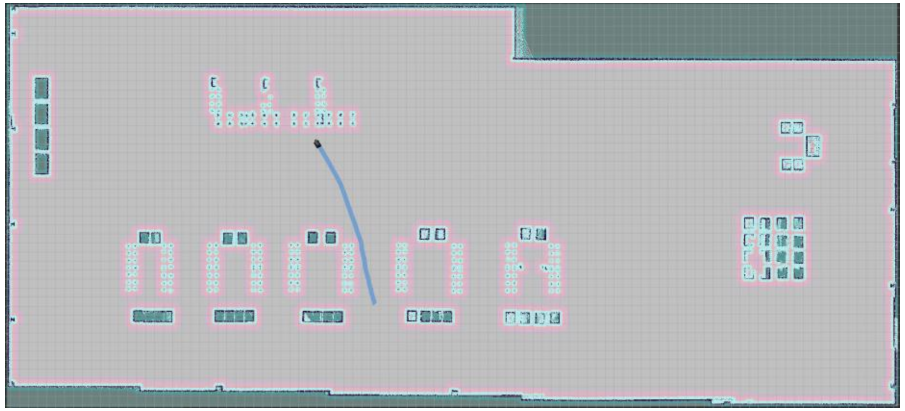
Metric map of the same location produced using conventional SLAM techniques



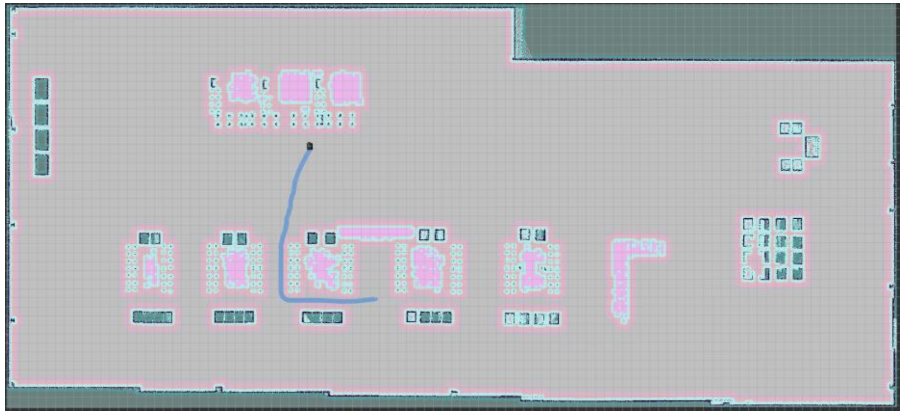
Occupancy probability for cells in the same location obtained from TPM

Proposed Method

- Navigation with life-long TPM maps:
  - Life-long map integration into the ROS navigation stack via:
  - Global costmap layer based on the probabilities from TPM to reduce replans and make navigation safer
  - Higher costs are assigned to cells with higher occupancy probabilities
  - Global path planning module plans around probably occupied areas



Global costmap displayed over metric map of the factory floor **without** TPM plugin loaded



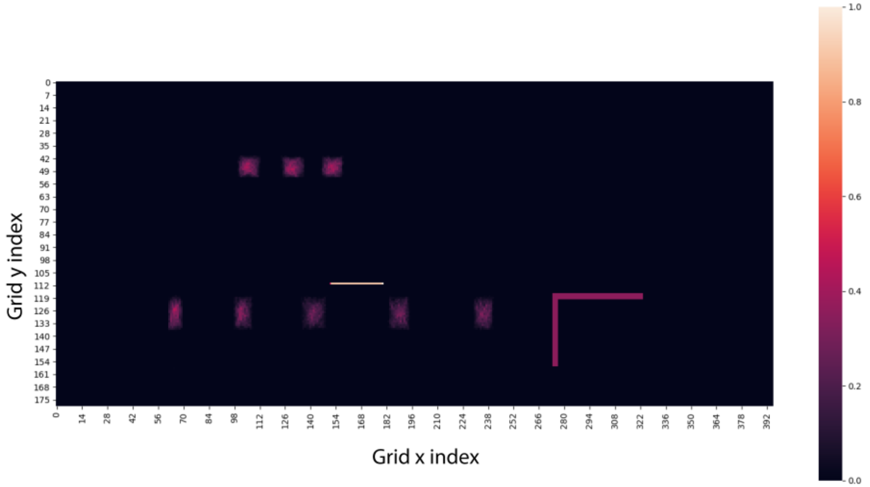
Global costmap displayed over metric map of the factory floor **with** TPM plugin loaded

Experimental Assessment

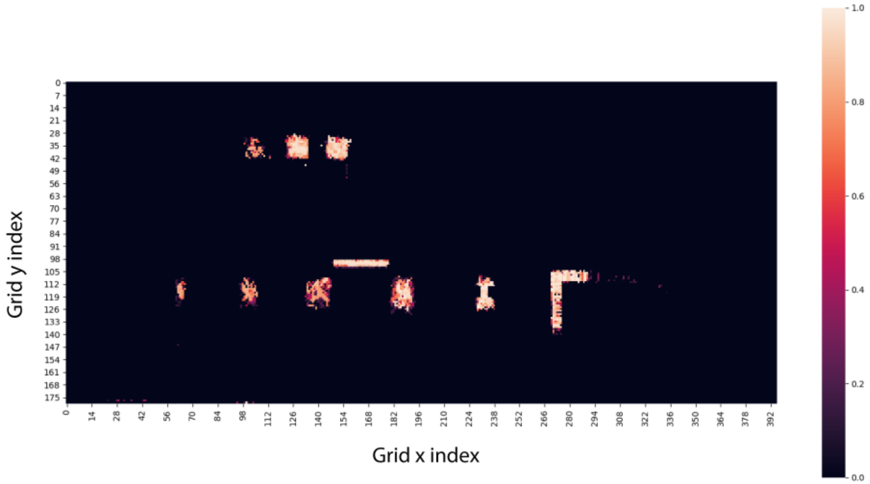
- A mobile robot was deployed in the simulated factory floor, where multiple worker models and a robot model were arbitrarily moving
- The initial static map of the factory floor was created by a robot using conventional SLAM techniques

Experimental Assessment

- TPM map evaluation:
  - A cell-by-cell comparison between the two heatmap grids, after compensating for the thinned lines obtained by simulated trajectories, showed **more than 95% accuracy** of the prediction of temporal persistence



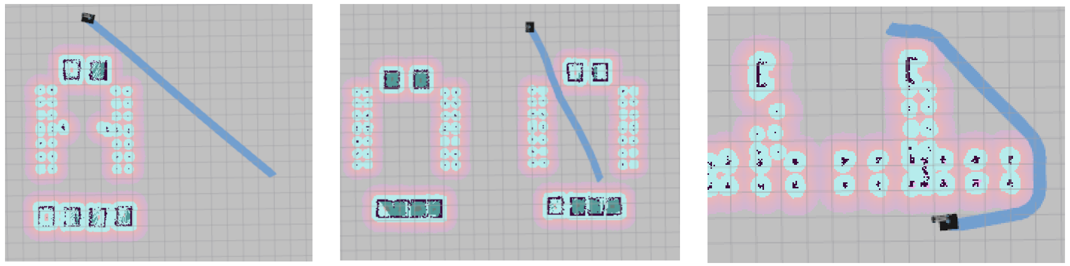
Mean occupancy of the map cells, derived from the known trajectories of the simulated models



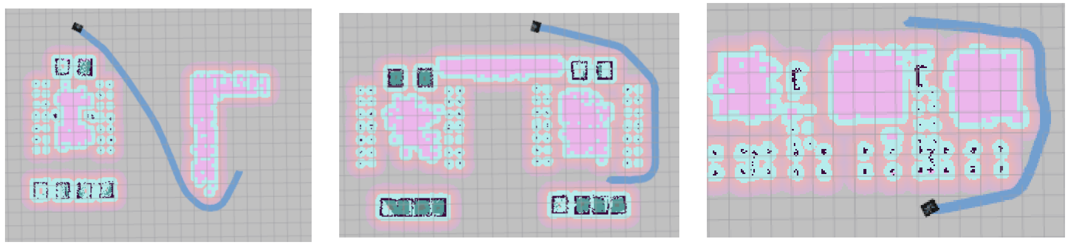
Predicted occupancy of each map cell, after employing TPM

Experimental Assessment

- Navigation with TPM evaluation:
  - **60% reduction in replans** due to high-traffic areas avoidance compared to navigation without TPM
  - Safer navigation in a dynamic environment



Produced paths by global path planner without the use of the TPM plugin



Produced paths to the same goals by global path planner **with** the use of the TPM plugin

Conclusions

- The probability of a cell to be “occupied" or “empty“ can be modeled, using sparse observations made by a robot
- Persistence of dynamic objects is modeled in a life-long map representation modeling thus traffic, congested and less occupied areas with efficiency
- The mobile robot can sufficiently avoid areas with highly persistent objects and prefer less congested areas in order to plan its trajectory

Acknowledgement

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Thank you!

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