Efficient Failure Detection for Mobile Robots Using Mixed-Abstraction Particle Filters

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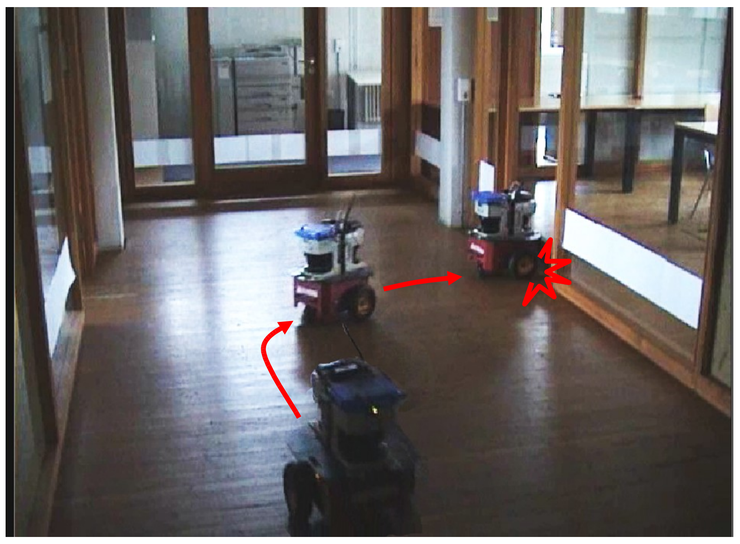
Overview

- A mobile robot should
  - detect failures quickly,
  - be able to infer the cause of a failure, and
  - be efficient in the failure-free case.

- We extend the Monte Carlo Localization scheme to simultaneously track multiple system models. Samples are distributed adaptively to the most appropriate models.



Mixed Abstraction Particle Filtering

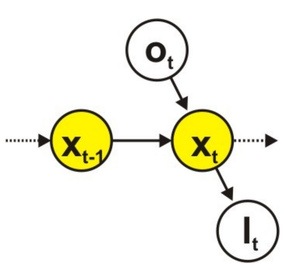
- Sequential State Estimation

$$p(x_t) = \eta_t \cdot p(z_t \mid x_t) \cdot \int p(x_t \mid u_{t-1}, x_{t-1}) \cdot p(x_{t-1})\, dx_{t-1}$$

Normalization · Observation model · Motion model · Recursive term

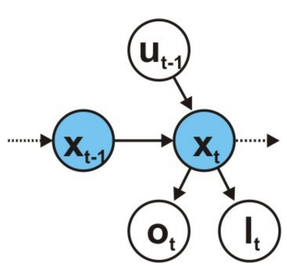
- We use multiple system models simultaneously, e.g.

Standard Model



- Odometry-based motion model
- Cannot handle failures
- Is efficient in the failure-free case

Dynamic Model

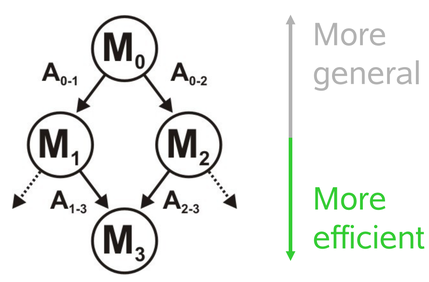


- Includes the motor commands
- Can handle certain failures, e.g.
  - Collisions
  - Deflating tires
- Is substantially more complex to compute

- The different models are related by considering the assumptions made about the state space.

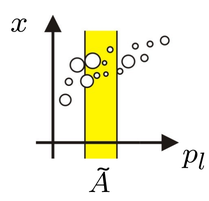
- For the state space $\{x, y, \theta, p_l, p_r\}$ which includes the tire pressures $\{p_l, p_r\}$, the standard model would for example assume that these are equal and constant.

- The models are organized in a model abstraction hierarchy that uses the explicit model assumptions
  - Edges: assumptions
  - Nodes: models



- The filter iteratively validates the model assumptions

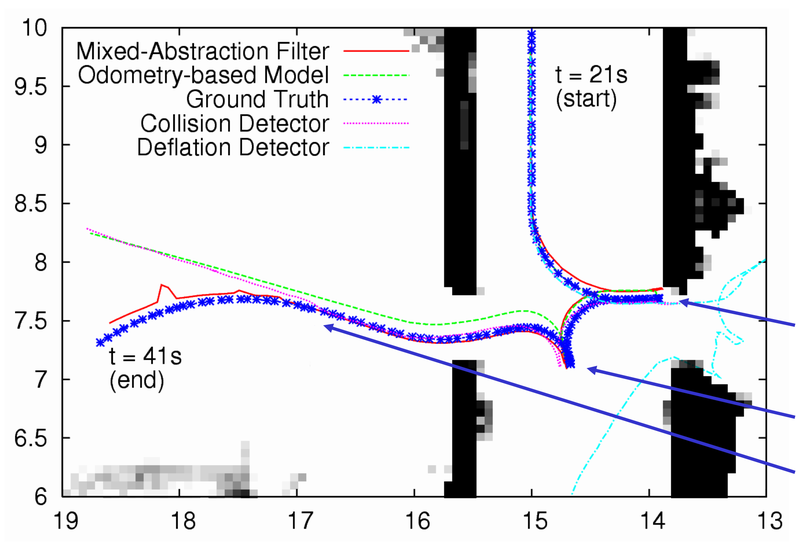
$$v_t(A) := \frac{\sum_{\tilde{A}} p(z_t|x^{[m]}) \frac{1}{|\tilde{A}|}}{\sum p(z_t|x^{[m]}) \frac{1}{|\mathcal{X}|}}$$



- and samples to the most efficient model which assumptions receive enough relative evidence

Experiments

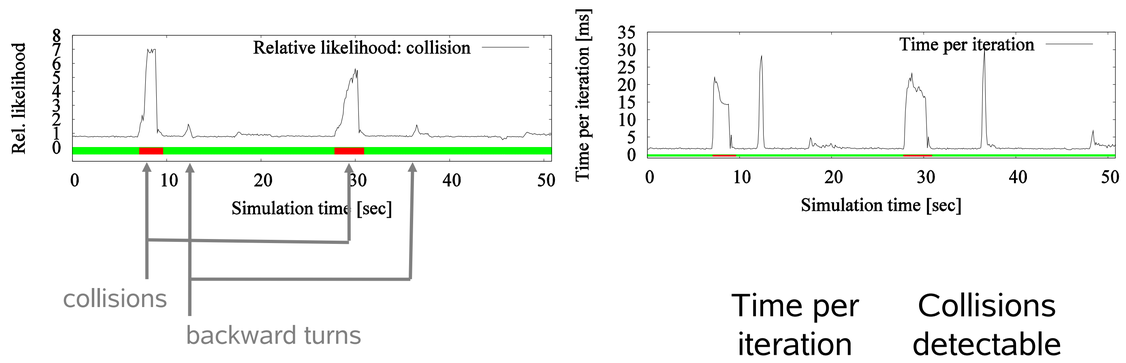
- Combining the standard model with a dynamic model for detecting collisions and one for deflating tires.



Three Events:

1. collision with glass door
2. backwards turn
3. deflation of left tire

- Analyzing the gain in efficiency



	Time per iteration	Collisions detectable
Standard model (20 particles)	0.67 ms	✗
Standard model (200 particles)	5.83 ms	✗
Dynamic model (300 particles)	10.10 ms	✓
Mixed Abstraction (Standard: 20, Dyn.: 300)	3.42 ms	✓

Conclusions

- The proposed system is able to combine multiple system models.
- Computational resources are distributed adaptively by verifying explicit model assumptions.
- Usefulness has been demonstrated in several failure detection settings.

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