Lifelong Exploration of Dynamic Environments

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As robots gradually leave the well-structured worlds of factory assembly lines and enter natural, human-populated environments, new challenges appear. The need to operate in less structured and more uncertain environments gave birth to probabilistic mapping, which enables the representation of incomplete world knowledge obtained through noisy sensory measurements. The combination of probabilistic mapping and planning methods lead to autonomous exploration [1] that allows the robots to create the environment models by themselves. However, as robots became gradually able to operate autonomously for longer periods of time, a new problem appeared – that the natural environments are subject to change. These changes manifest themselves through sensory measurements - every perceived environment change causes the sensory data to disagree with the original model obtained during the exploration phase. Although the probabilistic mapping methods can deal with the conflicting measurements, their handling is rooted in the idea that these are outliers caused by inherent sensor noise rather than by structural environment change. This has a negative impact on the ability of the mapping methods to deal with environment dynamics and provide support for long-term mobile robot autonomy.

Recently, some authors proposed to exploit these conflicting measurements in order to obtain information about the world dynamics and proposed representations that model the environment dynamics explicitly. These dynamic representations have shown their potential by improving mobile robot localization in changing environments [2], [3], [4], [5].

Similarly to traditional robotic mapping, introduction of spatio-temporal mapping methods requires spatio-temporal exploration. Unlike in classic exploration, where the finite size of the explored space causes the exploration task to be finite, exploration of dynamic environment is never finished and the robot has to plan not only **where**, but also **when** to perform observations that allow it to refine it's spatio-temporal map. We propose a novel exploration algorithm that extends information-based exploration paradigms in order to take into account the environment dynamics. Our exploration method gathers data at different places and times, integrates them in a dynamic environment model and uses the current model to reason about the most informative locations and times of the day. The proposed spatio-temporal exploration makes use of environment representations that model the dynamics and uncertainty of the environment states by their frequency spectra [3] obtained trough sparse observations. This dynamic model allows to predict the information gain obtained by observations of given environment locations at a given time, which allows the robot to plan where and when to gather measurements about the environment. The continuous update and refinement of the environment model enables a better reasoning over time, allowing the robot to gather more information about the environment compared to the models that consider the environment as static.

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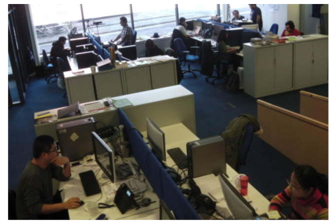
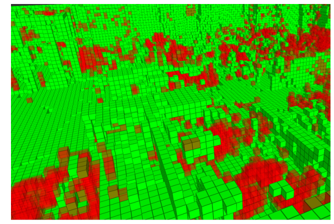


(a) L-CAS office view



(b) L-CAS spatio-temporal model

Fig. 1: Spatio-temporal occupancy grid of the Lincoln Centre for Autonomous Systems (L-CAS) office. The static cells are in green and cells that exhibit daily periodicity are in red.

The performance of the proposed spatio-temporal algorithm was evaluated both using real world datasets acquired over several months [6], but also through real world experiments, where we deployed a mobile robot over 5 business days in an office environment [7], see Figure 1. Results have shown that the robot is able to create and maintain models of the environment that change over time and, at the same time, it is able to gather more information than other exploration strategies.

References

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