Asynchronous Adaptive Sampling and Reduced-Order Modeling of Dynamic Processes by Robot Teams via Intermittently Connected Networks

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The main contribution of this work consists of the synthesis of reduced-order models (ROMs) of spatiotemporal processes using sparse sensor measurements with an intermittent communication framework for distributed robot teams. This allows for fewer robots to explore larger areas since maintaining network connectivity for all time is no longer required. The robots sample the spatiotemporal process by taking sparse measurements on their way to previously planned meeting locations, share their information at the meeting locations and distributively compute a ROM of the dynamic process being tracked. The ROM is used to estimate field values in areas without sensor measurements, which informs the path planning algorithm when determining a new meeting location for the team. This work presents an online, distributed adaptive sampling and modeling framework for robot teams that can only communicate in close physical proximity. It ensures asynchronous intermittent communication events as robots plan and execute paths in the workspace. The framework is demonstrated in simulation and compares different ROMs under full and intermittent connectivity. The simulation results demonstrate significant improvements in estimation accuracy even when communication is intermittent.

Distributed mobile robot networks have gained more and more interest in recent years due to their ability to cover larger areas and work together on a task. Their mobility and ability to carry sensor equipment makes them very wellsuited for the tracking and modeling of dynamic processes. Examples of processes of interest include the monitoring of ocean currents for efficient navigation of cargo ships, weather forecasting, wildlife and nature monitoring as in tracking of endangered animal populations or the distribution of plankton in an area of the ocean, and modeling of events like oil spills in the ocean or forest fire boundaries. In general, it is difficult to adequately capture the spatiotemporal dependencies of complex, nonlinear dynamic processes using only static sensors since optimal sampling locations can change over time, are unknown *a priori*, and may require large quantities of sensors to ensure proper coverage of the space. Mobile robots can mitigate this by adaptively changing their sampling locations which significantly reduces the number of required units for any given workspace and task.

Nevertheless, many of these spatiotemporal processes often occur at large spatial scales, in uncertain dynamic environments that are difficult to model, and are driven by a complex interplay of physical, chemical, and/or biological processes. This means that robots tasked to monitor these processes must not only be robust to failures, but also be able to operate with potentially significant communication constraints. Furthermore, in situations where only sparse measurement data is available, robots must have the ability to operate in a distributed fashion, often with intermittent network connectivity, while simultaneously extracting as much information from the obtained data in order to successfully estimate and track the process of interest.

The main contribution consists of the combination of ROMs with sparse sensor measurements with an intermittent communication framework for distributed robot teams. To the best of my knowledge, this is the first framework for distributed adaptive sampling and reduced-order modeling using an intermittently connected mobile robot communication network which could be extended to large-scale robot networks. The solution allows the efficient modeling of a dynamic process while guaranteeing communication between robots with constrained communication abilities. The ROM enables the robots to infer measurements of the dynamic process at unseen locations and to plan their paths efficiently in order to reduce their uncertainty in the estimation of the dynamic process. The algorithm can be scaled to larger networks of robot teams due to its inherent distributed nature and asynchronous updates. Finally, simulation studies show for different scenarios how the algorithm compares to fully connected robot frameworks and outperforms them.

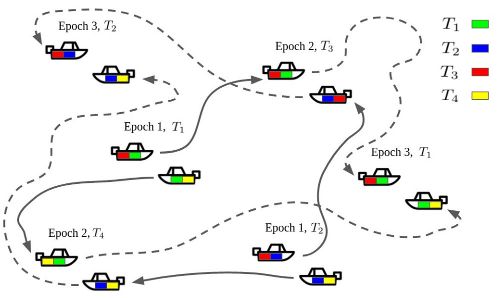

Figure 1: Schematic of the intermittent communication between 4 different teams (T_1 to T_4). Connected line corresponds to the first executed paths and the interrupted line to the second. After just 2 epochs the initial robot teams meet again and have gathered all the information from the other teams.

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