JAIST Repository
https://dspace.jaist.ac.jp/

Title	リソースに制限のあるマルチロボットによる環境モニタリングのための分散アクティブセンシング
Author(s)	Tiwari, Kshitij
Citation	
Issue Date	2018-03
Type	Thesis or Dissertation
Text version	ETD
URL	http://hdl.handle.net/10119/15336
Rights	
Description	Supervisor:丁　洛榮, 情報科学研究科, 博士

JAIST
JAPAN
ADVANCED INSTITUTE OF
SCIENCE AND TECHNOLOGY

Japan Advanced Institute of Science and Technology

氏 名	TIWARI, Kshitij
学 位 の 種 類	博士(情報科学)
学 位 記 番 号	博情第 382 号
学 位 授 与 年 月 日	平成 30 年 3 月 23 日
論 文 題 目	Multi-Robot Resource Constrained Decentralized Active Sensing for Online Environment Monitoring
論 文 審 査 委 員	主査 CHONG, Nak Young JAIST Professor
	MATSUMOTO, Tadashi JAIST Professor
	HO, Tu Bao JAIST Professor
	CHOI, Jongeun Yonsei University Associate Prof.
	CHOI, Han-Lim KAIST Associate Prof.

論文の内容の要旨

This thesis addresses the problem of trajectory planning over discrete domains for monitoring an environmental phenomenon that is varying spatially. The most relevant application corresponds to environmental monitoring using an autonomous mobile robot for air, water or land pollution monitoring. Since the dynamics of the phenomenon are not known a priori, the planning algorithm needs to satisfy two objectives simultaneously: 1) Learn and predict spatial patterns and, 2) adhere to resource constraints while gathering observations. Subsequently, the thesis brings the following contributions:

Firstly, it formulates a resource constrained information-theoretic path planning scheme called Resource Constrained Decentralized Active Sensing (RC-DAS) that can effectively trade-off model performance to resource utilization. Since, these objectives are inherently conflicting, optimizing over both these objectives is rather challenging. However, weighted combination of these objectives into a single objective function is proposed such that the total path length is bounded by the maximum operational range. This path planner is then coupled with a distributed Gaussian Process (DGP) framework to allow the robots to simultaneously infer and predict the dynamics of the environment of interest.

Secondly, optimal weight selection method is proposed wherein the weights of the RC-DAS cost function are dynamically updated as a function of residual resources. This extended scheme is referred to as RC-DAS† which additionally ensures that the robots return to base station at the end of their respective mission times. This prevents the robots from getting stranded amidst the field and is a first step towards making the architecture fail-proof.

Thirdly, an operational range estimation framework is proposed to interpret the bounds on maximum path

length attainable by the robots. This should be used as the limiting condition for terminating the exploration to ensure a safe path to the base station. This framework is then generalized to encompass various classes of robots and is made robust to operate with high accuracy even when subject to natural environmental disturbances like strong wind gusts or uneven terrains.

Fourthly, the RC-DAS framework is scaled to multiple robots operating in a fully decentralized fashion in communication devoid environments. Owing to such a setting, multiple inferred models of the environment can be obtained. However, neither all models can be fully trusted nor forthrightly rejected. To solve this dilemma and to obtain one globally consistent model, a pointwise fusion of distributed GP models is introduced and referred to as FuDGE.

Keywords: Active Sensing, Decentralized Multi-robot Teams, Resource Constraints, Map Fusion, Range Estimation.

論文審査の結果の要旨

This dissertation addresses the problem of informative trajectory planning for a decentralized team of mobile robots over discrete domains, monitoring an environmental phenomenon that is varying spatially. Since the dynamics of the phenomenon is not known *a priori*, the planning algorithm was designed to satisfy the following two objectives simultaneously: 1) learn and predict spatial patterns, and, 2) adhere to resource constraints while gathering observations. Specifically, the robots utilize the Resource Constrained - Decentralized Active Sensing scheme to select the most informative locations to observe while conserving allocated resources. A distributed Gaussian Process framework was used to split the computational load over a team of robots. Notably, the proposed Gaussian Process framework has been accepted for publication in the IEEE Transactions on Robotics, one of the most prestigious journals in the field of robotics.

In order for each of the robots to effectively deal with their finite battery resource, this dissertation also presented a methodology for identifying and quantifying the energy consumers, unifying the battery dissemination models into one framework that can estimate operational range for various robotic platforms. In contrast to existing works that focus on a pre-meditated mission profile and try to estimate the energy requirements for the mission, this work is considered the very first attempt to solving the inverse problem of optimizing the mission profile, given a fixed energy budget and known robot dynamics model by proposing the following two range estimation models: 1) an offline model which relies on the expertise of the operator for setting the prior information, and, 2) a self-reliant online variant that iteratively updates the operational range based on the real-time mission data. This part has also been provisionally accepted for publication in Mechatronics

(Elsevier), a prestigious journal of International Federation of Automatic Control.

This is an excellent dissertation and we approve awarding a doctoral degree to TIWARI, Kshitij.