Adaptive Sampling for Spatial Prediction in Wireless Sensor Networks

By

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Certificate of Original Authorship

I, Van Linh Nguyen, certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

Signature of Student:

Date:

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Acronyms and Abbreviations

WSN	Wireless Sensor Network
WSNs	Wireless Sensor Networks
GP	Gaussian Process
GPs	Gaussian Processes
SWSN	Stationary Wireless Sensor Network
SWSNs	Stationary Wireless Sensor Networks
MRWSN	Mobile Robotic Wireless Sensor Network
MRWSNs	Mobile Robotic Wireless Sensor Networks
MRWS	Mobile Robotic Wireless Sensor
MRWSs	Mobile Robotic Wireless Sensors
GMRF	Gaussian Markov Random Field
RMSE	Root Mean Square Error
RMSEs	Root Mean Square Errors
ARMSE	Average Root Mean Square Error
ARMSEs	Average Root Mean Square Errors
JOR	Jacobi Over-Relaxation
DAC	Discrete-time Average Consensus
H_2S	Hydrogen Sulphide
SPDE	Stochastic Partial Differential Equation
MI	Mutual Information
SA	Simulated Annealing
OF	Objective Function
MAC	Medium Access Control
VIED	Vietnam International Education Development

CAS	Center for Autonomous Systems
FEIT	Faculty of Engineering and Information Technology
UTS	University of Technology, Sydney

UNIVERSITY OF TECHNOLOGY, SYDNEY

Abstract

Faculty of Engineering and Information Technology

Centre for Autonomous Systems

Doctor of Philosophy

Adaptive Sampling for Spatial Prediction in Wireless Sensor Networks

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Networks of wireless sensors are increasingly exploited in crucial applications of monitoring spatially correlated environmental phenomena such as temperature, rainfall, soil ingredients, and air pollution. Such networks enable efficient monitoring and measurements can be included in developing models of the environmental fields even at unobserved locations. This requires determining the number of sensors and their sampling locations which minimize the uncertainty of predictions. Therefore, the aim of this thesis is to present novel, efficient and practically feasible approaches to sample the environments, so that the uncertainties at unobserved locations are minimized. Gaussian process (GP) is utilized to statistically model the spatial field. This thesis includes both stationary wireless sensor networks (SWSNs) and mobile robotic wireless sensor networks (MRWSNs), and thus the issues are correspondingly formulated into *sensor selection* and *sensor placement* problems, respectively. In the first part of the thesis, a novel performance metric for the sensor selection in the SWSNs, named average root mean square error, which reflects the average uncertainty of each predicted location, is proposed. In order to minimize this NP-hard and combinatorial optimization problem, a simulated annealing based algorithm is proposed; and the sensor selection problem is effectively addressed. Particularly, when considering the sensor selection in constrained environments, *e.g.* gas phase hydrogen sulphide in a sewage system, a modified GP with an improved covariance function is developed. An efficient mutual information maximization criterion suitable for this particular scenario is also presented to select the most informative gaseous sensor locations along the sewer system. The second part of this thesis introduces centralized and distributed methods for spatial prediction over time in the MRWSNs. For the purpose of finding the optimal sampling paths of the mobile wireless sensors to take the most informative observations at each time iteration, a sampling strategy is proposed based on minimizing the uncertainty at all unobserved locations. A novel and very efficient optimality criterion for the adaptive sampling problem is then presented so that the minimization can be addressed by a greedy algorithm in polynomial time. The solution is proven to be bounded; and computational time of the proposed algorithm is illustrated to be practically feasible for the resource-constrained MRWSNs. In order to enhance the issue of computational complexity, Gaussian Markov random field (GMRF) is utilized to model the spatial field exploiting sparsity of the precision matrix. A new GMRF optimality criterion for the adaptive navigation problem is also proposed such that computational complexity of a greedy algorithm to solve the resulting optimization is deterministic even with increasing number of measurements. Based on the realistic simulations conducted using the pre-published data sets, it has shown that the proposed algorithms are superior with appealing results.

To the memory of my dearest grandfathers and grandmother!