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Coverage control for distributed sensing networks

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1 Abstract

We describe decentralized control laws for the coordination of multiple vehicles performing spatially distributed tasks. The control laws are based on a gradient descent scheme applied to a class of decentralized navigation functions that encode optimal coverage and sensing policies. The approach exploits the computational geometry of Voronoi diagrams.

Our central motivation in this note is provided by distributed sensing networks in scientific exploration or surveillance missions. The motion coordination problem is to maximize the information provided by a swarm of vehicles taking measurement of some process.

1.1 Setting up the coverage control

Let $\{p_1, \dots, p_n\}$ be the location of n sensors moving in a Riemannian manifold (with boundary) Q. Let $\phi : Q \to \mathbb{R}_+$ be a distribution density function. The measure ϕ plays the role of an "information density". Assume each vehicle has a sensor that provides accurate local measurements and whose performance degrades with distance. Formally, let $f(\mathrm{dist}(q, p_i))$ (with 'dist' the distance defined through the Riemmanian metric) describe the performance degradation, e.g., noise, loss of resolution, etc, of the measurement at the point $q \in Q$ taken from the ith sensor at position p_i. The function $f : \mathbb{R}_+ \to \mathbb{R}_+$ is monotone increasing.

The overall "sensing performance" is given by,

$$U(p_1, \dots, p_n) = \int_Q \min_{i \in \{1,\dots,n\}} f(\mathrm{dist}(q, p_i))\, \phi(q) dq. \quad (1)$$

This function (common in geographical optimization science [1]) measures the ability of a collection of vehicles to provide accurate distributed sensing. The locational optimization problem is to minimize U.

1.2 Voronoi diagrams

Let the Voronoi region $V_i = V(p_i)$ be the set of all points $q \in Q$ such that $\mathrm{dist}(q, p_i) \leq \mathrm{dist}(q, p_j)$ for all $j \neq i$. The set of regions $\{V_1, \dots, V_n\}$ is called the Voronoi diagram for the generators $\{p_1, \dots, p_n\}$. When the two Voronoi regions V_i and V_j are adjacent, p_i is called a (Voronoi) neighbor of p_j (and vice-versa).

1.3 Decentralized control protocols

We propose the gradient descent as a decentralized control law that achieve "uniform coverage" of Q,

$$\dot{p}_i(t) = -\frac{\partial U}{\partial p_i}. \quad (2)$$

The following result [2, 3] shows that indeed the control law is decentralized, in the sense that only depends on local information, i.e. the location of p_i and of its neighbors,

$$\frac{\partial U}{\partial p_i} = \int_{V_i} \frac{\partial}{\partial p_i} f(\mathrm{dist}(q, p_i))\, d\phi(q). \quad (3)$$

Hence, U provides us with a decentralized navigation function [4] in the setting of multiple vehicle networks.

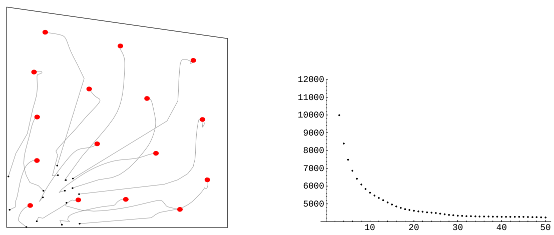

Figure 1: Distribution of sensors obtained by 16 vehicles in a polygon. The vehicles' initial positions are in a tight group in the lower left corner and their final positions are optimally distributed.

References

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