On Localizing Sensor Networks Based on Multilateration, Sensor Connectivity, and Seed Sensor Selection

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A Wireless Sensor Network (WSN) consists of numerous sensors which monitor physical conditions and communicate in an ad-hoc fashion. The data collected by the sensors are usually meaningful when coupled with their locations. Since equipping GPS modules is not cost effective for localizing sensors, the Sensor Network Localization (SNL) problem is aroused to localize sensors based on few known-position anchors and internode distances, and can be formulated as an unconstrained nonlinear optimization problem. Related works show that current challenges in SNL problem are error propagation and low computational efficiency, caused by large scale network and localization failure due to noisy distances.

The localizability test, as a tool to measure the difficulty for a SNL problem, can help avoid unnecessary computation in sensor localization and improve the deployment and control of WSN. The localizability for a sensor network is closely related to its global rigidity, but is not well-defined. To test the network localizability, we propose algorithm Loc_Idx to determine the localizability of each sensor, and accordingly classify sensors into three types, depending on their difficulties to be localized. Next, we propose a novel localization algorithm named Grad_MSA to localize sensors of different types by different methods. In particular, we first apply an iterative multilateration mechanism to localize those easily localizable sensors efficiently with small errors, and then localize the rest of sensors by a gradient descent mechanism based on a nonlinear mathematical programming model. Heuristics that use shortest path and local adjustment mechanisms are also applied to refine solutions.

Moreover, an anchor-free SNL problem is studied, which is beneficial for solving WSN containing unhelpful anchors and can generalize SNL algorithms to solve related problems such as graph realization or molecular conformation. We propose algorithm Grad_SS to localize anchor-free WSN by firstly selecting seed sensors, which are regarded as anchors in the process, localizing the rest of sensors with respect to the seed sensors, and then conducting linear coordinate transformation to calculate their original coordinates.

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Numerical experiments show each heuristics in Grad_MSA takes effect to improve the solution, and among them the iterative multilateration mechanism dominates high accuracy of localization. Compared with SFSDP (Kim et al. 2009) which solves a SNL problem by Semidefinite Programming, Grad_MSA performs better in both accuracy and running time of localization. For networks comprising the same number of nodes, the accuracy and speed of localization is positively related to its localizability. For solving an anchor-free SNL problem, several protein data are tested by Grad_SS and SFSDP with the results indicating the former performs much better than the other. It also reveals that Grad_MSA is able to localize large-scale network (containing more than 10,000 nodes) in 3D space within 3 minutes, and Grad_SS manages to solve the molecular conformation problem.

Several research topics are suggested for further investigation. The localizability test remains as an open problem since there is still no efficient method to identify all localizable sensors. With a robust algorithm of localizability test, we can generate SNL benchmark test cases of different localizabilities, so that SNL algorithms can be compared on a fair basis. Localizability tests can also help select optimal seed sensors for solving anchor-free SNL problems, which may be extended for solving other Euclidean distance geometry problems.

Keywords**:** Sensor Network Localization Problem, Localizability, Unconstrained Nonlinear Programming, Multilateration, Gradient Descent

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