3rd AIMMS-MOPTA Optimization Modeling Competition

Localization of ad-hoc sensor networks

Case study

Imagine the following scenario: Scientists want an accurate map of the distribution of some physical quantity (e.g., temperature, humidity, radiation level, vibration, etc.) over a large area with rough terrain or dangerous conditions. A possible solution is to drop off a large number of sensors roughly evenly distributed over the area. Besides measuring the environment, these sensors can communicate with each other and thus each of them can determine its distance from a few other sensors nearby. These distances are communicated throughout the network back to a base station. Using these pairwise distances scientists can locate each sensor and put their measurements on the map. Your team's task is to create a user-friendly system in AIMMS that carries out these operations.

1 Problem description

1.1 The base case

The basic problem is to find the location of a set of sensors given the pairwise distances between some of them. In the simplest case you can assume that all distance measurements are accurate and only pairs of sensors closer than some distance d can communicate with each other and thus provide a measurement. In other words, if there is no measurement between two sensors, they must be farther apart than d. To make the localization possible we also have a few anchor points, whose exact coordinates are known in advance. Anchors also communicate with their neighborhood the same way as sensors do.

1.2 Noise

There are two inherent sources of measurement noise when two sensors try to determine the distance between them. The first is the obvious inaccuracy of the measurement, but a second source is that two sensors in close proximity may not be able to determine their distance due to some obstacle between them. This will be referred to as a missing measurement.

1.3 Topography

In the simplest case the terrain is assumed to be flat. This is often not the case in practice, and the 3-dimensional case is bit more complicated than the 2-dimensional one. For the 3D cases you will be given the topography of the terrain in the form of a function defined over the area. All of the anchors and sensors are then assumed to be on the surface. Distances are measured as Euclidean (straight line) distances.

1.4 Temperature

Along with pairwise distance measurements you will be given temperature measurements for each anchor and sensor. You can use these to establish whether two sensors are near or far.

2 Goals

The goal of your optimization effort is to create a tool that allows the user to quickly and easily identify the location of as many sensors as possible and visualize the temperature data over the sensors. You should also try to find a way to quantify the accuracy of the localization. Note that in the presence of noise the accurate positions are impossible to find so aim for practicality instead of accuracy.

2.1 Software

A full version of the AIMMS modeling platform along with solvers CPLEX, GUROBI, MOSEK, XA, CONOPT, MINOS, SNOPT, LGO, AOA, PATH, and, through COIN-OR, CBC and IPOPT are provided to the teams free of charge. You may use any combination of these to solve the problem. We encourage all teams to take advantage of the procedural aspect of the AIMMS modeling system and solve the problems in multiple stages. Please study the documentation about the features and capabilities of these solvers.

If you have any questions about the software please contact mopta@aimms.com.

2.2 Data sets

We provide several datasets to help you develop your solution modularly:

2D, no noise: The base case, a flat plane, all distances between sensors with distance at most d are provided.

3D, no noise: The sensors lie on a 3-dimensional surface whose function is given. All straight-line distances between sensors with distance at most d are provided.

2D, noise: The sensors lie on a flat surface but the distance measurements are inaccurate and some of them are missing.

3D, noise: The most general case, the sensors lie on a 3D surface, the distance measurements are noisy and/or missing.

Developing a complete solution for the last case obviously includes all the previous ones, but we encourage you to progress gradually, as the easier problems have more accurate solution and can be solved more quickly. Feel free to submit your report even if you only have a solution for some of the easier cases. Depending on your approach you may find the third problem easier than the second one. In each case you will get a small and a large test set. The goal of this project is not to solve just these problems, but to implement a system in AIMMS that can solve any of these instances and interact with the user.

The data is structured as follows. Each data set containts three files:

`anchors.txt`
`distances.txt`
`temperature.txt`

The file `anchors.txt` lists the names and the locations of the anchors, one per line. For example `anchor1, 50, 100` indicates that there is an anchor point at $(50, 100)$ miles.

In the 3-dimensional case only the first two coordinates are supplied as the height can be computed from the topography function.

The file `distances.txt` contains the pairwise distances between sensors (and anchors) in miles. For example:

```
anchor1, sensor2, 50
sensor3, sensor4, 20
```

The file `temperature.txt` contains the temperature measurement (in Fahrenheit) for each anchor and sensor. The format is:

```
anchor1, 20.2
sensor1, 19.7
```

In addition, for 3D problems an extra file `topography.txt` will be provided with the coefficients `mx` and `my`, with unit miles. The format is:

```
mx, 30
my, 20
```

These coefficients are used in the following function for the surface of the terrain in feet.

$$h = 800 + 25 * cos(4 + 8 * x/my) + 50 * sin(y/my + 1) + 100 * x/mx * y/my$$

The variables `x` and `y` are in miles, as are `mx` and `my`, while `h` is in feet.

Filenames will also indicate the type and size of the problem. Your model will also be tested on different datasets, so please do not over-optimize for the given datasets. You do not need to use the above format in your model but make it easy to change the data and avoid hardwiring any constants in your model.

2.3 More information

You are free to browse the literature of sensor network localization if you need inspiration on possible approaches. It has been an active area for some time so there are a good number of papers and theses available about it.

3 Deliverables

Your team needs to deliver a complete solution to the problem described in this case study, including

- an implementation of the model in AIMMS, including a user interface, providing the user graphical and textual output;
- a solution of the models for the given data sets;
- a 15 page report about the mathematical background of the model, the solution techniques, results and recommendations.

The deadline for submission is June 15, 2011 23:59 EDT. If you have questions about the problem or the competition in general, please contact Frank E. Curtis at mopta@lehigh.edu.