

Poster Abstract: Cooperative Tracking with Binary-Detection Sensor Networks

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ABSTRACT

We present a novel method for tracking the movement of people or vehicles in open outdoor environments using sensor networks. Unlike other sensor network-based methods, which depend on determining distance to the target or the angle of arrival of the signal, our cooperative tracking approach requires only that a sensor be able to determine if an object is somewhere within the maximum detection range of the sensor. We propose *cooperative tracking* as a method for tracking moving objects and extrapolating their paths in the short term. By combining data from neighboring sensors, this approach enables tracking with a resolution higher than that of the individual sensors being used. We employ statistical estimation and approximation techniques to further increase the tracking precision, and to enable the system to exploit the tradeoff between accuracy and timeliness of the results. We analyze the behavior of the cooperative tracking algorithm through simulation, focusing on the effects of approximation techniques on the quality of estimates achieved. This work focuses on acoustic tracking, however the presented methodology is applicable to any sensing modality where the sensing range is relatively uniform.

Categories and Subject Descriptors

J.m [Computer Applications]: Miscellaneous

General Terms

Algorithms, Performance, Experimentation

Keywords

target tracking, cooperative tracking, sensor networks

1. INTRODUCTION

Sensor networks are built from small, inexpensive devices that provide modest computational capabilities and short-range sensing. The sensors used by these devices account for a substantial portion of their cost, an important metric

for very large scale sensor networks. Thus it is important to explore the capabilities of sensor networks that provide only the most basic sensing. Such simple sensors have only the ability to detect whether a signal is present within some fixed range of the sensor, providing only single-bit detection result and no additional information. We call such systems *binary-detection sensor networks* and study the tracking problem in this setting.

Several target tracking algorithms have been proposed for sensor networks where sensors provide distance or angle of arrival information, *e.g.* [3]. Such techniques are inapplicable in binary-detection sensor networks. While proximity sensors used in these networks do not encounter the types of measurement errors typically present with angle of arrival, distance and signal strength-measuring sensors, the resolution of signal location from these sensors is significantly lower. *Cooperative tracking* allows us to improve the precision of tracking by exchanging information among neighboring sensors to refine the target location estimates. We present a two-level cooperative tracking algorithm that provides tracking precision better than can be achieved by simple averaging of the sensor readings to estimate the target position.

Our simulation studies show that a high degree of precision and scalability is achieved by the algorithm. We validate these simulation results with a small-scale prototype implementation of a binary-detection acoustic tracking system that uses the cooperative tracking approach.

2. COOPERATIVE TRACKING

In cooperative tracking, each sensor detects the presence of the target in their vicinity, and this information is shared among nearby nodes to improve the accuracy of the target location estimate. We introduce a novel two-phase approach to this problem. First, local target position estimates are computed. These estimates are then aggregated and used to compute the path of the object, which produces a more precise estimator for the target location.

In the first phase, sensor nodes exchange the times when the target signal is detected and the duration of detection and compute a location estimate for each time point. Initially, it is set to be equal to the location of the sensor. As information from other sensors becomes available, the

position estimate is recomputed as a weighted average of the sensor locations, using the inverse of the estimated perpendicular distance from the sensor to the target's path as the weight. The weight for node i is assigned according to Equation 1, where R is the maximum detection radius, v is the estimate of the target's speed, t_i is the duration for which the target has been detected by i , and f is the sensor sampling frequency. The weights are then normalized and the final location estimate is computed. Due to this weighting scheme, sensors that lie closer to the path of the target receive more weight.

$$w_i = \frac{1}{\sqrt{R^2 - 0.25v^2 * (t_i - f^{-1})^2}} \quad (1)$$

In the second phase of the algorithm, we compute a piecewise linear approximation of the path using a line-fitting algorithm on the position estimates obtained in the first phase. Since this computation exploits the spatial and temporal separation of the detected signals, the target location derived from the path estimate is actually *more precise* than the original target position estimates used to compute the path itself. We thus achieve tracking with a resolution higher than that of the individual sensors in the network.

The network continuously aggregates the position estimates provided by the sensors, which are used to update and refine the path estimate. By adjusting the number of position estimates used for the computation of each line segment, our algorithm can exploit the tradeoff between timeliness and precision of the results to satisfy the needs of the application. The timeliness metric is particularly important for "convergence" applications, where sensing is coupled to real-time control [1]. Since the number of position estimates can be adjusted dynamically at run time, early rough estimates of the path can be computed for time-critical tasks and then refined later on.

3. RESULTS

We studied the performance of the cooperative tracking algorithm through simulation. The following model is used to represent the sensor network and the tracked object.

The object moves through the sensor network at a constant speed of $1 R/s$, where R is the nominal maximum detection range of the sensors. The actual sensor range varies from $0.8 R$ to $1.2 R$ according to a uniform distribution. The separation between sensor nodes in the network is $1 R$. Since we express the main parameters, object's speed and sensor density, in terms of the sensor radius R , the results can be generalized to tracking objects traveling at different speeds by changing the density accordingly.

The two-level tracking approach has relatively high target location error, near $1 R$, when the object is first detected or changes course drastically. However the location error falls to below $0.2 R$ of the sensing radius within 4 seconds of initial detection. This increase in precision can be attributed to the refinement of the path and position estimates by the second phase of the algorithm as more spatially-distributed position estimates are gathered.

Prior research indicates that for many sensor network applications, performance is not substantially degraded by node localization error within 0.2 of node separation distance [2]. Our cooperative tracking algorithm provides comparable precision for the location of the target, thus it can be

used under similar conditions. Statistical estimation techniques can be employed to further improve the tracking precision.

There is a linear relationship between target movement speed and accuracy. The desired balance between accuracy and timeliness of the results can be achieved by setting the size of position estimate history kept by the sensors, given the sensor density and target speed as parameters. It can also be adjusted dynamically using feedback control.

To validate the simulation results, we created a prototype acoustic tracking system using binary-detection cooperative tracking. The sensor network is composed of 16 Berkeley motes with standard sensor boards that include a microphone. The microphone is used to detect a unique acoustic signature emitted by the tracked object. The average detection range of the microphones is scaled down to approximately 0.5 meters, which is the node separation distance in the experiment. The performance of this small-scale experimental system is largely consistent with simulation results. This provides experimental validation of the simulation methodology, while simulations of up to 1000 nodes demonstrate the scalability of the approach.

4. CONCLUSION

Our cooperative tracking algorithm uses only the simplest possible sensors, however it achieves a high degree of precision. The tracking precision is comparable to cooperative tracking approaches that rely on distance or angle of arrival measurements from the sensors. The key to achieving such performance is using the approximation of the path, computed cooperatively by the sensors, to refine the position estimates of individual sensors. This result enables sensor network-based tracking with binary-detection sensors, which are much simpler and thus cheaper than distance-measuring sensors or sensor arrays used for determining the angle of arrival.

An in-depth discussion of the binary-detection cooperative tracking approach, including simulation and experimental results and analysis, is presented in [4].

5. REFERENCES

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