Public Abstract
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Title:ASYMPTOTICALLY EFFICIENT ESTIMATORS FOR GEOMETRIC SHAPE FITTING AND SOURCE LOCALIZATION

The primary object of this thesis is to provide solutions to the important and challenging nonlinear estimation problem. The nonlinear estimation problem is not trivial to solve because there is only an implicit rather than explicit relationship between the observed data measurements and the unknown parameters to be estimated.

In this thesis new solutions are derived for two important nonlinear estimation problems: the circle and ellipse fittings, and the source localization via a collection of spatially distributed sensors. They are similar to each other in a way that their measurements only have nonlinear relationships with respect to the unknown parameters we are interested in. Digital signal processing techniques have been applied to the nonlinear estimation problem in order to provide a computational effective, efficient and most importantly, closed-form solution.

The major contributions of this thesis are:

a) A new Maximum likelihood (ML) estimator based on Taylor-series linearization under Gaussian white noise is developed and compared with the Full least-square (FLS) method. Unlike the result from a previous work cite{Chan05}, it has be shown here that the FLS method only approximates the ML estimator if the ratio between noise power and circle radius square is much less than unity.

b) The semi-definite programming (SDP) and the semi-definite relaxation (SDR) techniques are applied to the circle fitting problem. The SDP and SDR are two powerful tools in solving optimization problem and they have been shown to be computationally efficient. In this thesis the ML cost function and constraints are re-formulated and relaxed so that the nonlinear estimation problem can be solved using a new SDP method, which provides the optimum global convergence solution.

c) Computational efficient solutions for concentric circles and concentric ellipses fittings are derived. The new estimators have explicit forms and can produce both non-iterative and iterative solutions. The non-iterative solution has better computational efficiency than the other existing non-iterative methods. The iterative solution is self-initialized and provides optimum performance. It also has higher noise tolerance level for the thresholding effect comparing to other existing iterative methods. The new estimators can be reduced back to the fitting of a single circle and a single ellipse.

d) For the research regarding to the source localization in the presence of sensor position noise, based on the TOA measurement the degradation in accuracy of the source location estimate is analyzed theoretically. The analysis indicates how sensitive is the source location estimate with respect to the sensor position errors. A new closed-form solution that accounts the sensor position errors and achieves the CRLB performance is derived.

e) A joint estimator for locating multiple unknown sources and refining the erroneous sensor positions using

TOA measurements is proposed. Rather than resorting to the traditional iterative nonlinear ML estimator that requires careful initializations and high complexity, the new estimator is algebraic and computationally attractive. Other than the estimation of the source locations, the proposed method can refine the inaccurate sensor positions which can improve the localization accuracy of newly appeared sources subsequently.

f) It is common believe that ignoring the uncertainties of sensor position when estimating the source location will result in non-optimum estimation performance. However, with further investigation this thesis shows the relations of the sensor position and measurement noise covariance matrices for TOA, TDOA and AOA localizations, under which taking into the sensor position errors into account is not necessary and does not improve the localization accuracy. In such cases, a calibration emitter with known position is needed to limit the damage due to the sensor position errors. Its optimum placement position is derived for the TOA, TDOA and AOA measurements with independent, identical distributed (IID) or very significant sensor position noise relative to the measurement errors. When the optimum calibration placement may not be possible in practice, a suboptimal but practical calibration placement criterion is provided.