Chapter 10
Conclusions and Further Research Directions

Undoubtedly, the optimization and control of DPSs are intensively expanding research areas with a high number of applications. The process of data acquisition, being an integral part of control design, is fundamental since in distributed systems it exerts a strong influence on the accuracy of estimation, the quality of control and prediction of system behavior. Therefore, sensor networks, being, in fact, modern observational systems which have recently emerged in the context of monitoring distributed processes, are becoming a very important field of research. Their advantageous features related to distributed sensing and data fusion, robustness to faults and failures of sensor nodes, as well as flexibility in realization of the measurement process facilitate wide applicability of such systems. Nevertheless, the problem of sensor scheduling for parameter estimation in DPSs is very difficult since its intrinsic nonlinearity rather excludes simple methods. Furthermore, most often, the dependence between the observations and the system performance is not intuitive and has obscure or confounding nature. Despite these facts, the problem has been considered by many authors and a number of relevant contributions have already been reported in the literature. In addition to this, some new approaches to determining optimal sensor locations are still proposed in order to provide a more general context, a wider range of potential criteria and better understanding of the interconnection between optimal sensor routing and the quality of the identifiers. On the other hand, engineers expect efficient techniques which are easy to implement and provide benefits overcoming the cost of the application.

In such a way, although various results for the sensor scheduling problem exist, engineers seem to be reluctant to apply them in practice. This is a direct consequence of the complexity of most sensor location approaches, which lead to sophisticated and inefficient algorithms. Moreover, the existing methods are often intricate and difficult to implement. However, taking into account that the progress in computational mathematics combined with the rapidly increasing computer power steadily extend the range of potential applications, there is a strong necessity to develop more effective systematic
approaches which would pave the way to algorithms of great efficiency and reasonable complexity.

Bearing this in mind, the original objective of the research reported in this monograph was to develop effective and reliable methods to solve the sensor scheduling problems encountered in a wide class of practical applications for monitoring DPSs using sensor networks or sensor arrays. In order to accomplish this task the appropriate theoretical substantiation for the adopted approach was developed. Furthermore, some known methods were generalized and several new algorithms constructed. The following is a final concise summary of the contributions provided by this work to the state-of-the-art in optimal sensor scheduling for parameter estimation in DPSs:

- Systematizes and generalizes the classical results of optimal experiment design for stationary sensors to MIMO systems with possible output correlation.
- Develops expeditious methods of activating scanning sensors, and in particular:
  - extends the theory and adapts some algorithms of nonlinear programming and optimal experiment design to solve sensor activation problems;
  - introduces an approach based on clusterization-free designs for an arbitrarily fixed switching schedule and develops an extremely efficient exchange algorithm, which is very easy to implement;
  - transforms the problem to the equivalent Mayer problem of optimal control in the case of an optimized switching schedule and adapts some recently developed techniques of discrete-valued optimal control (the CPET transform) for its solution.

- Formulates and solves the problems of trajectory planning for sensor networks with mobile nodes:
  - refines Rafajłowicz’s approach to constructing optimal trajectories of moving sensors; derives optimality conditions for nonparameterized and parameterized trajectories;
  - extends Uciński’s approach to sensor path planning towards design of resource aware sensor routing strategies; specifically, it is shown how to reduce the problem to a state-constrained optimal-control problem including alternative objectives related to the network resources or behavior (i.e. energy limits, path lengths, coverage, etc.);
  - develops the method of sensor routing for heterogeneous sensor networks adapting the concept of continuous experimental designs and applies the two-phase first-order algorithm to construct optimal trajectories of mobile nodes.