UNIVERSITÀ DI PISA

DIPARTIMENTO DI INGEGNERIA DELL'INFORMAZIONE

Dottorato di Ricerca in Ingegneria dell'Informazione

Doctoral Course

"Introduction to Statistical Estimation Theory with Applications to Automation and Robotics"

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Short Abstract: Modern ICT applications are increasingly asking for systems with a relevant level of autonomy. Applications for Industry 4.0, for Internet of Things (IoT) or for service robotics, to mention a few, are gaining more and more attention nowadays. The ability to carry out complex tasks is critically related to the ability to retrieve meaningful information coming from the available sensors. To this end, it is mandatory to understand how a measurement process can be analytically described and how the sensorial data can be manipulated to extract the quantities of interest with the highest possible precision, i.e., the best estimate. This problem becomes even more challenging in dynamic environments when multiple systems interact together, e.g., robotic systems. In this course, the notions needed to correctly model a measurement process will be firstly introduced. Then, an introduction to Bayesian and non-Bayesian classic estimators will be given. Two of the most popular estimators will be studied in details for linear and nonlinear systems: the Weighted Least Squares and the Kalman Filter. Examples of applications such as clock synchronisation, state estimation for Smart Grid as well as localisation for single or multiple robots will be presented. Finally, a discussion on other state-of-the-art solutions for localisation as well as on implications for closed-loop systems in the presence of uncertainty will be offered.

Course Contents in brief:

- Background on Statistics: Probability, Random variables, Multivariate Pdfs, Conditional and Marginal pdfs, Propagation of error, stochastic processes
- Data analysis and estimation algorithms (Maximum Likelihood (ML), Least Squares (LS), Maximum A Posteriori (MAP), Minimum Mean Squared Error (MMSE))
- Linear and nonlinear Weighted Least Squares and Kalman filtering, with applications to automation and robotics
- Distributed estimation for team of robots with distributed Kalman Filters

Total # of hours: 20

References:

[1] Y. Bar-Shalom, X. Rong Li ,T. Kirubarajan: “Estimation with Application to Tracking and Navigation - Theory, Algorithm and Software”, John Wiley and Sons, 2001.

[2] Kia, Solmaz S., Stephen Rounds, and Sonia Martinez. "Cooperative Localization for Mobile Agents: A Recursive Decentralized Algorithm Based on Kalman-Filter Decoupling." IEEE Control Systems 36.2 (2016): 86-101.

CV of the Teacher

Daniele Fontanelli received the M.S. degree in Information Engineering in 2001, and the Ph.D. degree in Automation, Robotics and Bioengineering in 2006, both from the University of Pisa, Pisa, Italy. He was a Visiting Scientist with the Vision Lab of the University of California at Los Angeles, Los Angeles, US, from 2006 to 2007. From 2007 to 2008, he has been an Associate Researcher with the Interdepartmental Research Center ``E. Piaggio'', University of Pisa. From 2008 to 2013 he joined as an Associate Researcher the Department of Information Engineering and Computer Science and from 2014 the Department of Industrial Engineering, both at the University of Trento, Trento, Italy, where he is now an Associate Professor. He has authored and co-authored more than 150 scientific papers in peer-reviewed top journals and conference proceedings. He is an Associate Editor in Chief of the IEEE Transactions on Instrumentation and Measurment and an Associate Editor for IEEE Robotics and Automation Letters and for the I ET Science, Measurement & Technology. His research interests include real-time control and estimation, resource aware control, localisation and tracking algorithms, service robotics, synchrophasor estimation and clock synchronisation algorithms.

Room and Schedule

Room: *????*

Schedule:

Day I – Morning (4h):

Recap on Statistics: Sensors and sensor calibration, Statistics of measurement processes, Probability, Random variables, Multivariate Pdfs, Conditional and Marginal pdfs, Propagation of errors, White processes, Markovian processes

Day I – Afternoon (3h):

Estimation Algorithms: Minimum Variance Unbiased Estimators, Cramer-Rao lower bound

Day II – Morning (4h):

Estimation Algorithms: Best linear unbiased estimator

Non-Bayesian Estimators: Maximum Likelihood estimation, Weighted least squares solutions, The (Non-linear) Weighted Least Squares

Matlab: Application of the Least Squares in Distributed Systems

Day II – Afternoon (3h):

Bayesian Estimators: Maximum A Posteriori, Minimum Mean Squared Error, The (Extended) Kalman Filter

Matlab: Application of the Kalman Filter for target tracking

Day III – Morning (3h):
Estimation problems in robotics: Static and dynamic state estimators
Collaborative localisation: Observability analysis and cross-covariance issue, observability issues and consistency for Kalman filters in collaborative localisation

Day III – Afternoon (3h):
Distributed estimators: Distributed WLS and distributed Kalman filter with Consensus theory
Matlab: Distributed target localization for WSNs