IPIN 2023 Tutorial Proposal: Indoor Localization using Magnetic-Fields

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***Abstract*—The ambient magnetic-field is a highly informative source for indoor localization. It is omnipresent and variations in the field, if measured accurately, provide a fingerprint highly correlated to the measurement location. These variations in the field are caused by ferromagnetic material, which is present in more or less any building, e.g., due to steel in the construction of buildings. Hence, the magnetic-field constitutes a viable and robust source for localization in GNSS denied environments. Still, the full potential of magnetic-field localization remains largely unexploited in practice. This tutorial aims to make the concept of magnetic-field localization more accessible for researchers and practitioners in the field.**

This tutorial provides an overview of how magnetic-fields, together with contemporary sensing and information fusion technologies, can be used to enable scalable, accurate, and robust indoor localization solutions. The tutorial comprises 3 lectures from skilled researchers and lecturers within the field, extending the general magnetic-field localization concepts, with the special topics of magnetic-field odometry, and magnetic-field based simultaneous localization and mapping (SLAM). These lectures are complemented with a demonstration illustrating key concepts and a hands-on session in which the participants can construct a Gaussian-process based magnetic field map using data collected from a smartphone.

Target audience:	Researchers and practitioners with an interest in indoor navigation
Keywords:	magnetic-field localization, simultaneous localization and mapping (SLAM), sensor fusion, odometry
Length:	180 min (30+45+45 min lectures + breaks/demos)
Required resources:	Lecture hall with projector and WiFi. We also ask the participants to bring their laptops with a working installation of either Python or Matlab.

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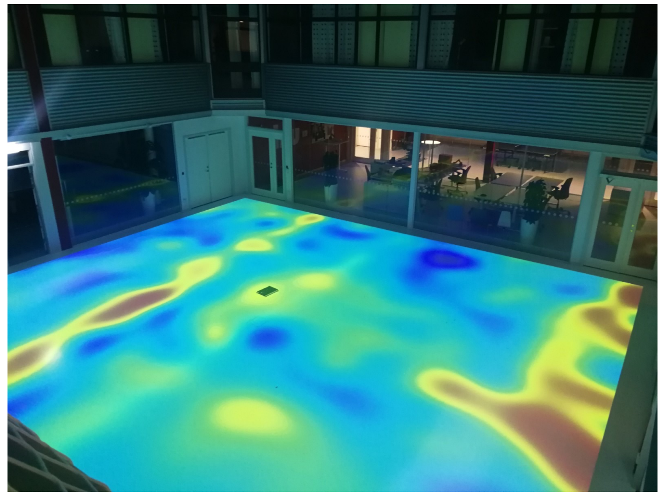

Fig. 1. Illustration of the magnetic-field potential variations inside a building.

I. Tutorial Aim & Planed Activities

The overall goal of the tutorial is to give the participants an overview of how magnetic-field measurements, together with contemporary sensing and information fusion technologies, can be used to enable scalable, accurate, and robust indoor localization solutions. Focus will be on presenting the key concepts behind magnetic-field finger-printing, mapping, odometry, and simultaneous localization and mapping (SLAM). Further, the physical properties of magnetic-fields will be reviewed and different methods to model and learn magnetic-fields on a macro- and micro-scale, will be presented. Open research problems and practical challenges will also be highlighted.

The tutorial will consist of three standard lectures (30+45+45 min), where the material is presented using powerpoint presentations and videos. Further, two technical demonstrators, of which one will be hands on for the participants, will be used to illustrate taught theories and concepts.

II. Tutorial Outline

Lecture #1 (30 min):
Introduction to Magnetic-Field Based Localization

- The potential of magnetic-fields based indoor localization
- In what ways can we use magnetic-fields for localization
  - Tracking of magnetic objects
  - Finger printing and mapping
  - Odometry
  - SLAM
- Active vs passive magnetic-field localization systems
- Properties of magnetic-fields and magnetic-field models
  - Attenuation and distortions
  - Divergence- and curl-free fields
  - Macro- & micro-scale models
- Practical challenges in measuring and working with magnetic-fields

Leg Stretcher (5 min)

Lecture #2 (45 min): ***Magnetic-Field Based Odometry***

- Basic idea behind magnetic-field based odometry
- Common approaches:
  - Differential equation solution approach
  - Model parameter estimation approach
- Models and estimation methods used in the model based approach to magnetic-field based odometry
  - Gaussian-process models
  - Polynomials models
  - Sum-of-dipole models
- Theoretical performance bounds
- Videos of magnetic-field based odometry
- Fusion with other sensors and information sources
- Reflection and research challenges

Demo #1 (15 min): ***Magnetic Source Localization***

- Real-time visualization of magnetic-fields and magnetic-object localization using an array of magnetometers.
- In parallel coffee break

Lecture #3 (45 min): ***Magnetic-Field SLAM***

- Basic idea behind magnetic-field SLAM
- Common approaches
  - Finger printing (discrete space features for loop-closure)
  - Mapping (continuous magnetic field map)
- Map representations:
  - Gaussian processes representation
  - Computational complexity considerations
  - Inclusion in state-space models
- Examples of experimental results
- Reflection and research challenges

Hands-On Session (40 min):
Constructing Magnetic Field Maps

- Hands-on session on constructing Gaussian-process based magnetic field maps using data collected from a smartphone.

III. Biographies

Gustaf Hendeby received the M.Sc. degree in applied physics and electrical engineering in 2002 and the Ph.D. degree in automatic control in 2008, both from Linköping University, Linköping, Sweden.

He is Associate Professor and Docent at the division of Automatic Control, Department of Electrical Engineering, Linköping University. He worked as Senior Researcher at the German Research Center for Artificial Intelligence (DFKI) 2009–2011, as Senior Scientist at Swedish Defense Research Agency (FOI) and held an adjunct Associate Professor position at Linköping University 2011–2015. His main research interests are sensor fusion and stochastic signal processing with applications to nonlinear problems, target tracking, and simultaneous localization and mapping (SLAM), and he is the author of several published articles and conference papers in the area. He has experience of both theoretical analysis as well as implementation aspects.

Dr. Hendeby is since 2018 an Associate Editor for IEEE Transactions on Aerospace and Electronic Systems in the area of target tracking and multisensor systems, and since 2021 leader of the WASP Localization and Navigation Area Cluster. In 2022 he served as general chair for the 25th IEEE International Conference on Information Fusion (FUSION) in Linköping, Sweden. He was elected to the ISIF Board of Directors 2023–2025.

Manon Kok received the M.Sc. degrees in Applied Physics and in Philosophy of Science, Technology and Society, both from the University of Twente, Enschede, The Netherlands, in 2009 and 2007, respectively, and the Ph.D. degree in Automatic Control from Linköping University, Linköping, Sweden, in 2017. From 2009 to 2011, she was a Research Engineer with Xsens Technologies. From 2017 to 2018, she was a Postdoctoral with the Computational and Biological Learning Laboratory, Machine Learning Group, University of Cambridge, Cambridge, U.K. She is currently Assistant Professor with the Delft Center for Systems and Control, Delft University of Technology, the Netherlands. Her research interests include probabilistic inference for sensor fusion, signal processing, and machine learning.

Isaac Skog received the B.Sc. and M.Sc. degrees in Electrical Engineering from the KTH Royal Institute of Technology, Stockholm, Sweden, in 2003 and 2005, respectively, the Ph.D. degree in Signal Processing with a thesis on low-cost navigation systems in 2010, and the Docent degree in Signal Processing from the KTH Royal Institute of Technology in 2015. In 2009, he spent five months at the Mobile Multi-Sensor System Research Team, University of Calgary, Canada, as a Visiting Scholar. In 2011, he spent four months at the Indian Institute of Science (IISc), Bengaluru, India, as a Visiting Scholar. In Fall 2017, he joined the Automatic Control Group, Linköping University. He was a recipient of the Best Survey Paper Award by the IEEE Intelligent Transportation Systems Society for the article (In-Car Positioning and Navigation Technologies—A Survey) in 2013