Localization and Scalability for Distributed Autonomous Systems
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Accurate localization – of vehicles, robots, humans, and gadgets in both the absolute and relative sense – is a fundamental component in achieving high levels of autonomy. Scalability is another fundamental component in advanced autonomy and an enabler for future localization systems.

Vision for the Project

Background: Localization and scalability are both crucial for all future autonomous systems, including autonomous functions and self-driving vehicles, indoor positioning systems, Internet of Things as well as asset management and many other industrial applications. The challenges in these applications include high complexity, cost reductions, distributed cloud computations and high demands on position accuracy and integrity. Scalability is ubiquitous in all autonomous systems, in particular cloud-based localization systems where many trade-offs are needed in the optimization, and where the future number of users and nodes are more or less unlimited in many applications.

Objective: Our domain expertise offers a toolbox of algorithms and solutions for localization challenges, and our research aims at analyzing their efficiency in terms of accuracy and integrity for different sensor configurations (cost perspective) and implementation constraints (distributed cloud, time delays, constraints, etc). The span of these challenges goes all the way from very high integrity in aircraft navigation to low demands in personal devices, from high accuracy in self-driving cars, law-enforced accuracy in personal navigation, to user-defined acceptable performance in VR-tools.

Connection to other WASP Projects: One important application domain is of course autonomous systems in vehicles, such as self-driving cars and future safety systems, so ATS (Automated Transport Systems) is naturally connected. IPLVIAS includes many central sensor fusion concepts that also apply to localization. It is anticipated that many future localization systems are implemented in the cloud, or are cloud-assisted, so the Autonomous Cloud project is highly relevant. Situational awareness is crucial in all decision support systems, and particular in sensor rich environments the localization is a challenge, so there is a close connection to ICAASE. Further, the scalability aspect occurs and is an important aspect in all projects on autonomous systems.

Future Demonstrations: The LARA arena at LiU and the indoor arena at KTH are tailor-made to validate localization algorithms on a small scale. Both include a well defined indoor environment where ground truth reference systems are available. However, localization eventually needs to be evaluated in the real environment. Our industrial partners have access to suitable arenas in many different environments, from vehicles operating underground to in the air. We have had some five regular workshops since 2011 where we invite industry to participate in our presentations and see our live demos, a tradition we will continue with under the WASP umbrella.

Research Challenges

There is a rich literature today on localization accuracy for certain technologies, where GPS of course is a mature area, and cellular radio, ground sensor networks and navigation systems in all kind of vehicles are also well explored. Integrity (robustness and availability over time and space) is thoroughly researched for GPS, but much less explored in the latter applications above, while it is a key performance index for all industrial applications of localization. This is one area we want to explore, by using a sensor fusion and learning approach, where redundancy and large data sets are tools to achieve our goals. Cloud solutions including crowd sourcing concepts provide promising ways to access large amount of data from various sensor modalities. New sensor technologies and radio standards offer a steady stream of new sensor fusion challenges, and old paradigms have to be revised for each technology leap. Centralized off-line sensor fusion solutions provide upper bounds on performance, while distributed real-time implementations on incomplete data streams frame our research themes.
For the scalability issue, an important research challenge is to develop methodology and tools for design of large-scale networked autonomous systems using distributed control and optimization. The philosophy is to enforce local dynamics and interactions that enable the use of scalable methods for design and analysis at the global level. Such local properties could for example be passivity or monotonicity. For many systems this can be done without performance loss compared to centralized control. In other cases, distributed solutions are preferable due to simplicity and robustness. Another research challenge is to analyze the interaction between economic incentives and technological constraints. This is already a widely recognized issue in the context of power transmission and energy markets, but is increasingly relevant also in road traffic where dynamic road tolls and car sharing platforms are interacting with congestion dynamics on the roads.

Our PhD sub-projects all relate to these key questions, from both a methodology and an application oriented point of view.

**Industrial Challenges**

The research challenges above have strong connections to both automotive industry and communications industry as well as distribution networks and manufacturing. One main challenge for our industrial partners is to provide domain expertise which leads to relevant research goals, including specifications of feasible hardware, on-going standardization efforts and performance needs for their future localization systems. Besides the companies with industrial students, we also had applications from BT Trucks and Atlas-Copco. Localization is of industrial relevance for many other Swedish companies such as Volvo Cars, Volvo Trucks, Volvo CE and Scania for autonomous vehicles, hospitals and manufacturing industries for asset management, infrastructure for traffic, logistics, water, gas, electricity and building control, etc. Localization is also a hot topic in the gaming industry and AR and VR applications. We also mention that we have a number of successful spin-offs in the area of localization, including Combain Mobile and MAPCI from Lund, Senionlab and NIRA Dynamics from Linköping, and the OpenShoe project and 13th Lab from KTH.

**Sub-projects**

**Large-Scale Optimization for Distributed Control**

*Shervin Parvini Ahmadi, LiU*

This PhD project will investigate network topology such as hierarchical network structure, e.g. chordal graphs, for scalable and rigorous robustness analysis and the extension of this towards hierarchical and distributed control synthesis. We will also study how privacy affects the achievable performance and what amount of communication that is needed between different computational agents in order to achieve the most efficient overall computations. Relevant applications are within infrastructure networks for traffic, water, gas, electricity, and building control. In this project we primarily focus on applications within power grids. Contacts have been established with ABB Corporate Research in Switzerland.

**Advanced real-time planning and decision making for autonomous systems**

*Kristoffer Bergman (industrial student), SAAB and LiU*

This project aims at developing state-of-the-art real-time planning and decision making algorithms that we believe will play a key-role of the “intelligence” of future autonomous systems. We would like to, as far as possible, to work model based and minimize situation and platform specialization, as well as operator involvement. The algorithms should themselves find solutions, i.e., a sequence of decisions in time, to the given problems formulated in the form of a user-defined mission objective, constraints on behaviors and actions, and a model of relevant parts of the world (updated in real-time from observations and communication) where the platform acts.
Distributed autonomous systems for localization and mapping

Andreas Bergström (industrial student), Ericsson and LiU

In this project we will investigate and develop new methods and software for modeling, analysis and design of interconnected control systems that: 1) Scale well with problem size, 2) Can be implemented in a distributed fashion, and 3) Respect privacy. The choice of wireless communication strategy has big impact on what performance can be achieved. The context in which we will study the above is a distributed autonomous system for localization and mapping.

Management of Distributed Autonomous Systems

Per Boström (industrial student), SAAB and LiU

Previous works related to this research area have covered coordination (trajectory planning) of multiple heterogeneous flying sensor platforms in order to optimize tracking performance of ground targets. This project will also make use of an aerial vehicle system-of-systems setting, but rather than trajectory planning it will be focused on autonomous resource management and how the sensors in a network of flying autonomous systems should cooperate to obtain an overall situational awareness.

Localization using large arrays of inertial sensors

Håkan Carlsson, KTH

This project considers the use of large arrays of low cost integrated inertial sensors to form cost efficient virtualized high performance sensors through local sensor fusion. Such sensor arrays will both offer new sensing modalities as well as through redundancy the ability to self-calibrate during operation. The research challenges in this project relate both to classical questions applied to the new sensor structures such as parameter identifiability – what can be measured and corrected for in a given array – and also the development of computationally efficient optimization procedures for the high dimensional and typically non-convex optimization problems that arise in the parameter estimation step of the sensor fusion.

Localization and Monitoring of Vehicles supported by Inertial Sensors

Martin Lindfors, LiU

This PhD project investigates how cheap inertial sensors can be used to monitor wheeled vehicles. One aspect is to estimate the speed of the wheels, and use this in an odometric navigation system. Another aspect is to monitor the driveline for faults and the road/track state. Field test data are obtained from NIRA Dynamics and the roller-coaster Wildfire and Kolmården Zoo. The research includes new ways to pre-process almost periodic signals to suit a sensor fusion framework.

Control using Distributed Observers

Hamed Sadeghi, LU

In this project we will investigate how the quality of state estimators impact the performance of distributed controllers. This is well understood in the classical centralized setting, but less so in the context of distributed control. Applications in autonomous systems will be considered, where local state estimators are used for control by individual agents and we are interested to know how the interaction between agents is influenced by local estimation errors.

Discriminative Learning & Optimization in Radio Access Networks

Vidit Saxena (industrial student), Ericsson and KTH

This project will study the merger of discriminative learning techniques with more classical generative modeling for the optimization of radio access networks, with the overall goal of making future radio assess networks more autonomously deployable and self-tuning and thus inherently more scalable. The research challenges relates to the study of the availability and use of training data automatically labeled though by the exiting radio network control infrastructure; and to answer fundamental questions of how to merge black box approaches from discriminative learning with white box approaches of generative learning to form new grey box modeling approaches for radio access networks.
Positioning in Underground Mines

John Svensson (industrial student), Boliden and LiU

This PhD project concerns localization in mines co-habited with humans and machines using different radio technologies. The research targets both autonomous driving and safety aspects. Collaborations with Ericsson for 5G technologies and Cisco for next generation WiFi products serve as drivers for research. There is a rich literature on sensor networks, with generic scenarios with agents (moving) and anchors (stationary), while we here have a unique application that fits the standard models, but adds all aspects of a real application, that is believed to lead to a revised set of research questions.

Robot mapping

Jiexiong Tang, KTH

The main scenario for this robot mapping project is a flying robot equipped with a set of sensors such as cameras and laser scanners. The focus will be on mapping where GPS or other infrastructure solutions to localisation is not available. The environment can be anything from a structured indoor setting such as an office building to a tunnel or mine, probably with an emphasis on indoor environments. Two avenues for research are initially envisioned both connected to a long-term autonomy scenario. One is to study how to improve the model over time, for example, by increasing geometric accuracy, more details in textures, and by associating common structures across space and time. Another one is to study how to extract and incorporate semantic information into the map and to explain as much of the data in it as possible by, for example, being part of objects.

Autonomous mission system for mobile production system fleet

Max Åstrand (industrial student), ABB and KTH

This project aims at achieving new methods and software for modeling, analysis and design of large fleet connected autonomous (or high automated system with operator in the loop) systems using control and optimization techniques. It will be applied on real-time coordination for distributed mobile production system build on tools from model based estimation, short term dynamic scheduling and rescheduling algorithms. It will also consider condition based machine maintenance for optimal machine availability, real-time positioning localized for accurate transport time and others.