Title

The Design and Validation of Algorithms and Software for Cooperative Navigation, Tracking and Mapping in GPS Denied Environments

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Application domains which this paper addresses:

Unmanned Aerial Vehicles (UAVs), Flight control, Communication, Navigation, and Surveillance (CNS) systems

Topics which this paper addresses:

- Methods: Verification and validation (V&V), Experimental platforms, Metrics
- Systems Issues: Metrics for the definition of system of system performance (cooperation)
- Emergent Issues: Adaptive non-deterministic systems

Background

Almost all UAV systems rely on the use of GPS (coupled with INS) as the mechanism for attaining absolute knowledge of location of the platform. With the assumption that the navigation problem is solved, most research and demonstration work on cooperative tracking and mapping focuses on inter and intra vehicle control strategies. However, a navigation technique known as Simultaneous Localisation and Mapping offers the potential for UAV systems to localise, navigate, track and map without the need for GPS. It requires detailed and robust mathematical and software approaches to both data fusion and control since the vehicle is required to make active decisions about what features/targets to observe for both satisfying the mission objectives as well as to attain accurate self-localisation estimates. The USAF is currently interested in the concept of using such an approach for tasks involving multiple UAVs undertaking the cooperative tracking and mapping of environments where GPS is denied and our research in this area has led towards an understanding of what areas require formal methods to validate and prove both the consistency/stability of the localisation system as well as the stability of the overall system to meet the mission objectives. These methods have focussed both on the mathematical approaches in defining the hybrid nature of the estimation and control functions and its instantiation into software, as well as asking questions into proving concepts of "mission stability" and how one can verify the stability and performance of a complex adaptive system such as that depicted here.

It is this project backdrop which is used to answer the questions below, however the answers are generic to any adaptive cooperative system.

Addressing the three questions:

1. What are the three most important challenges?
    a. Algorithmic structures (and their proofs) which couple hybrid estimation and hybrid control – across many platforms – and the software validation and verification of such structures.
    b. Defining metrics both at the platform and mission levels which characterize the attributes of a cooperative UAV system. The implementation of statistical techniques which allow for the evaluation of these metrics in real time and thus provide a

mechanism for the online system performance of adaptive systems, as well as real time system re-configurability.

   c. Developing scientific formalisms of the notion of "mission stability" for cooperative adaptive systems and using these formalisms to develop proofs/techniques/tools which would be used as part of the software engineering signatory process.

2. What are the three most important information technology research needs?
   a. Intelligent and adaptive communication routers: In the system described above there is a need to ask what information should be sent to whom and when. These are common questions to ask in many cooperative adaptive systems. Information which contributes towards the understanding of the real time global performance of the system is important. Intelligent routers which can adaptively change links according to communication specifications and mission stages would allow for real time mission performance understanding.
   b. Operating systems and software architectures for distributed software programming: Such architectures need to be light on memory and computational requirements, and must meet hard-real-time needs. They should also allow for robust middle-ware implementation, not requiring detailed knowledge of the underlying code structure.
   c. Software architectures for hard-real-time hybrid estimation and control: Being able to validate in simulation, then Hardware in the Loop testing, followed by real demonstration, all in the same software environment, would dramatically reduce time to deployment as well as software integrity. This software needs to effectively instantiate hybrid estimation and control algorithms, and ideally do so using graphical methods in a middle-ware framework.
3. What is a possible roadmap for the next 5 to10 years?

- 2007 – 2010
  - Operating system software architecture for hybrid estimation and control. Graphical deployment as well as ability to distribute code automatically as a function of computational and memory requirements.
  - Mission real-time support for the validation of the software instantiation.
  - Intelligent communication routers which form adaptive links based on communication specifications and mission stage.
  - System metric analysis and demonstration.
  - (Project Specific – Demonstration of cooperative control strategies in an adaptive probabilistic mission environment, and with GPS denial.)
- 2011-2014
  - Developing a system notion of mission requirements which the system "understands".
  - Real time mission performance monitoring and adaptive real-time re-configurability of software and assets to meet mission needs.
  - (Project Specific – Real time deployment of cooperative UAVs in a GPS Denied Environment, undertaking mapping and tracking missions).