A Logical Framework for Self-Optimizing Networked Cyber-Physical Systems

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An Application Framework for Networked CPS

- Based on new loosely-coupled distributed computing model:
  - Partially Ordered Knowledge Sharing
- Inspired by our earlier work on delay-disruption-tolerant networking (DTN)
- Minimal assumptions on network connectivity can be very unreliable
- Works with dynamic topologies, network partitions, and mobile nodes
- Designed for heterogeneous networking technologies and heterogeneous nodes
- Partial order allows the network to replace obsolete or subsumed knowledge
- Global consistency is not enforced (impossible in challenging environments)
- Avoids strong non-implementable primitives, e.g. transactions
- Locally each cyber-node uses an event-based model with local time
- Events are local, but knowledge can be shared and cached in the network
- Each cyber-node can have attached cyber-physical devices

Framework supports
- model-based simulation
- probabilistic analysis algorithms
- real-world deployment/execution
- visualization of simulated NCPS

Distributed Logic for Declarative Control

- Truly distributed logical framework with explicit proof objects
- Cyber-predicates enable interaction with the physical world
- Facts and goals treated on an equal footing
- Covers entire spectrum between autonomy and cooperation
- Tested with abstract mobility model and Stage multi-robot simulator
- Soundness, Completeness, and Termination Conditions

Networked Quadcopter Testbed

- Quadcopters are a very interesting class of cyber-physical devices (equipped with many sensors and actuators including cameras)
- Networked quadcopters will allow us to perform collaborative tasks (e.g. formation flying, distributed sensing, monitoring)
- Quadcopters (and their components) become devices in the cyber-application framework
- Currently controlled from a network of netbooks on the ground (each node can control one or multiple quadcopters)
- Can be equipped with gusmatic SBC and additional devices (e.g. GPS, digital compass) for more autonomy
- Currently experimenting with vision-based localization for indoor-usage (see pictures below)

Parallel and Distributed Optimization

- Distributed and parallel meta-heuristic framework combining
  - an existing mature sequential optimization framework (Opt4J) with
  - a loosely coupled distributed island model for scalable parallelization
- The parallelism is transparently provided by the cyber-framework
- cyber-nodes cooperate by emitting waves of knowledge, which interfere
  until all local solutions asynchronously converge to a global solution
- Optimization fits well into the partially ordered knowledge-sharing model
- Replacement order is defined by either
  - single objective function (solution fitness) or
  - multiple objective functions (Pareto optimality)
- Algorithm: population based meta-heuristic optimizer utilizing the island model
- Case study: design space exploration of an embedded multimedia system
- Key features: scalability and robustness in the optimization problem
- Optimizer performance is studied on Internet-wide testbed (Planet Lab)
- Possible next steps:
  - Combining optimization and declarative control
  - Use of weighted/quantitative/probabilistic logic
  - A small-scale real-world deployment (e.g., formation flight of quadcopters)