CPS: TTP Option: Synergy: Collaborative Research: Dependable Multi-Robot Cooperative Tasking in Uncertain and Dynamic Environments

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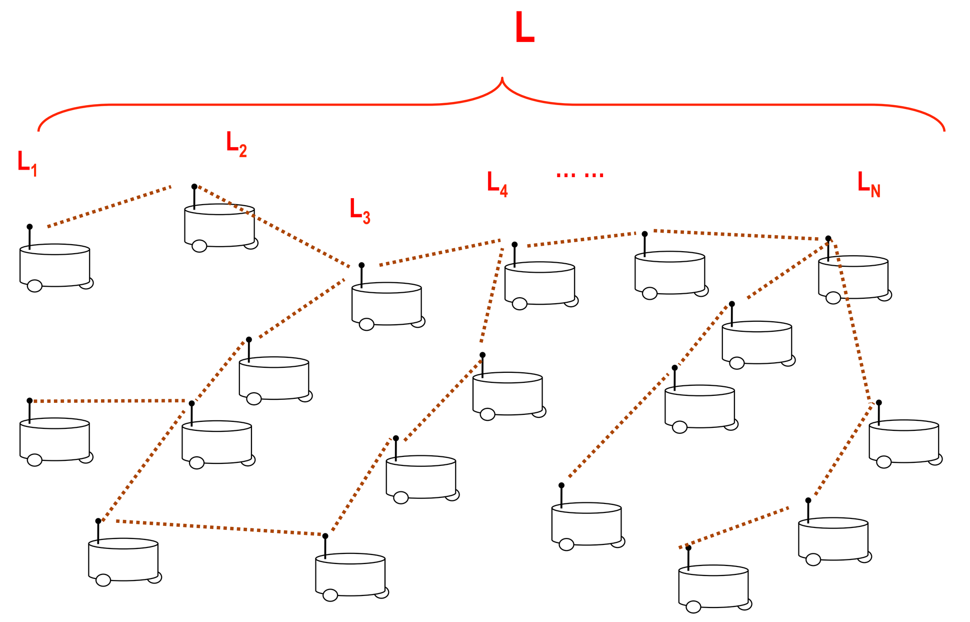
Project Overview

Driven by both civilian and military applications, such as coordinated surveillance, search and rescue, underwater or space exploration, manipulation in hazardous environments, and rapid emergency response, cooperative actions by teams of robots has emerged as an important research area. This project focuses on fundamental theory studies so to enable a scalable, correct-by-construction formal design of multi-robot systems that can guarantee the accomplishment of high-level team missions through automatic synthesis of local coordination mechanisms and control laws. Furthermore, results from the research can be extended to the design of more general cyber-physical systems (CPSs) consisting of distributed and coordinated subsystems, such as the national power grid, ground/air traffic networks, and manufacturing systems. These CPSs are critical components of the national civil infrastructure that must operate reliably to ensure public safety. The multidisciplinary approach taken will help broaden participation of underrepresented groups in research and positively impact engineering education.

Project Objectives and Approach

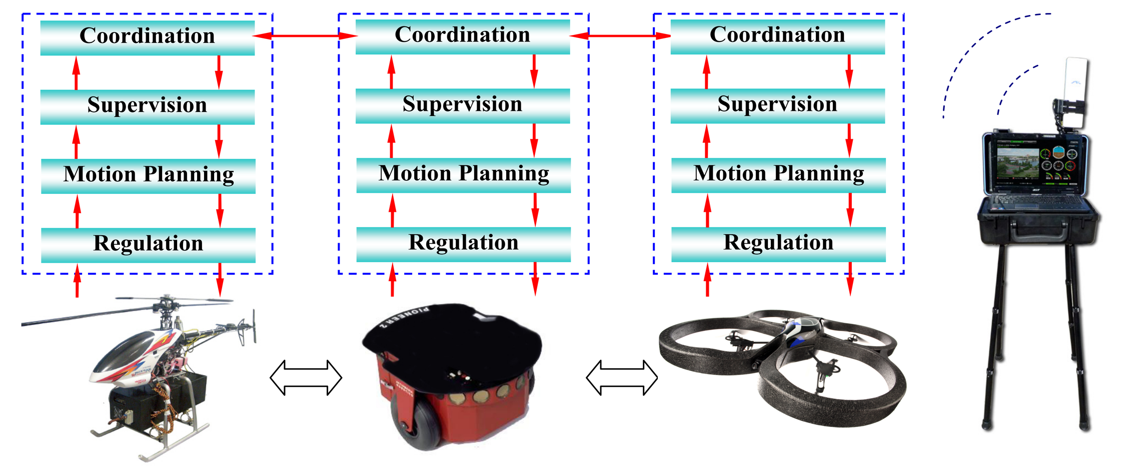
Goal: Focusing on multi-robot teams, the goal of the research is to build foundations for a provably correct formal design theory for CPSs. This design theory will guarantee a given global performance of multi-robot teams through designing local coordination rules and control laws.

Basic idea is "divide-and-conquer." First, we decompose the team mission into subtasks for individual robots, and then synthesize a local supervisor individually for each robot to fulfill these subtasks.



Multidisciplinary approaches combining hybrid systems, supervisory control, regular inference and model checking will be utilized to achieve this goal.

Hybrid Hierarchal Control



Different from the majority of existing work, such as swarming robotics, behavior based robotics, multi-agent system etc., we are interested in developing a formal correct-by-design method for distributed coordination and control of multi-robot systems consisting of heterogeneous robots in uncertain environments.

For such a purpose, we adopt a hybrid hierarchical control architecture that helps to manage the complexity of controlling heterogeneous robots, and to meet the requirements on flexibility and re-configurability.

Compared with existing architectures, the architecture proposed here is different due to its emphasis on distributed automatic synthesis for guaranteed multi-robot cooperative tasking based on a unified hybrid system theoretic framework.

Hence our research tasks include:

Objective 1. Automatically synthesize supervisors for uncertain discrete-event plants.

Objective 2. Automatically derive subtasks for individual robots from a given team mission.

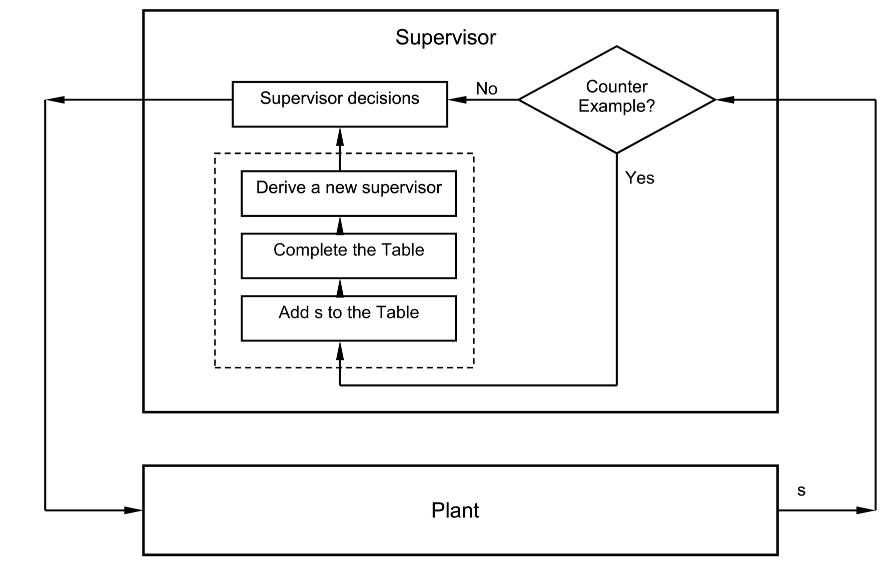
Objective 3. Implement and demonstrate the top-down design approaches on real robotic systems.

The developed theory will enable robots in the team to cooperatively learn their individual roles in a mission, and then automatically synthesize local supervisors to fulfill their subtasks.

A salient feature of this method lies on its ability to handle environmental uncertainties and unmodeled dynamics, as there is no need for an explicit model of the transition dynamics of each agent/robot and their interactions with the environment.

In addition, the design is online and reactive, enabling the robot team to adapt to changing environments and dynamic tasking. The derived theory will be implemented as software tools and will be demonstrated through real robotic systems consisting of unmanned ground and aerial vehicles in unstructured urban/rural areas.

Automatic Synthesis

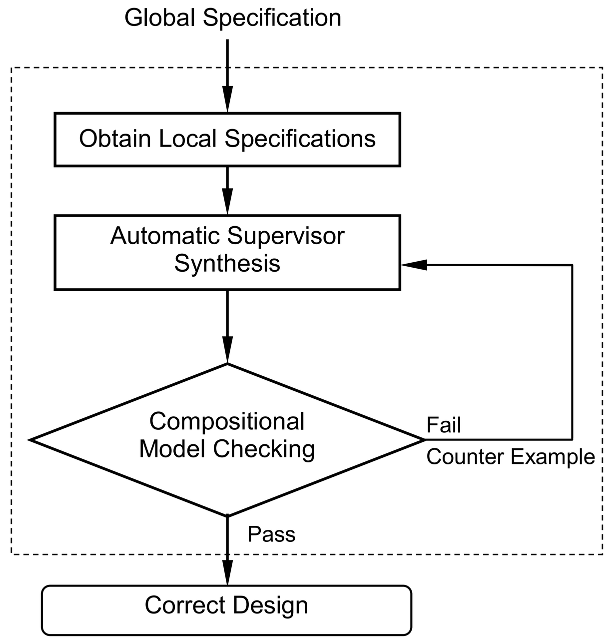


The supervisor layer design needs an automatic synthesis method that can guarantee the achievement of logic specifications from coordination layer with only partial knowledge of the plant model.

For this we combine machine learning and hybrid supervisory control theory. Our basic idea is to use the control specification to guide the learning process by deciding whether a certain run respects the specification or not. Runs that violate the specification are called counterexamples, and are used to tune the supervisor. The updated supervisor is then used until a new counterexample occurs, based on which a new supervisor is obtained.

Task Decomposition and Team Coordination

The challenges in the coordination layer design lie on the need to be distributed and automated.

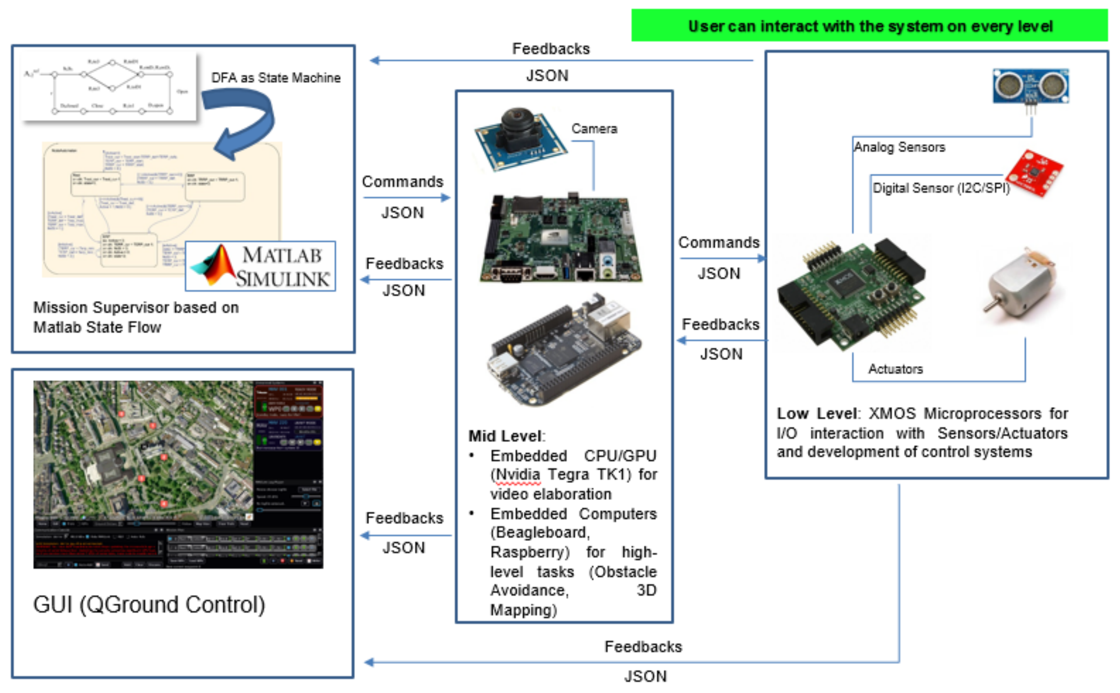


Initially, the global specification is used to guide the local synthesis, and then the assume-guarantee reasoning is employed to check whether the current design satisfies the global specification. If not, the model checker will generate counterexamples that can be used to redefine individual tasks and re-synthesize supervisors accordingly. After supervisor re-synthesis, the assume-guarantee reasoning is performed again and the co-design process repeats until no further counterexamples are found. The co-design process can also be triggered by new counterexamples on-the-fly due to the change of environments or occurrence of failures. Hence, the proposed design approach can adapt to changing environments and dynamic tasking as the design is distributed, automated and reactive.

Robot Testbed Development

The DU Unmanned Systems Laboratory (DU2SL) of the School of Engineering and Computer Science (SECS) has a large complement of ground and airborne platforms instrumented with state of the art sensors and custom-made general purpose navigation controllers. The current fleet of available unmanned aircraft includes more than 17 aerial platforms used for experimental proof-of-concept-demonstration.

The current efforts focus on upgrading both hardware and software design so to: Enforce strict real-time performance; Each node/agent must be able to interact with a different library/suite of sensors simultaneously (sensor information fusion); The (collaborative robot team) system must be modular and scalable, as well as adaptable even when new agents join or leave the team; The 'supervisory control' system must be event-driven and able to interact with all agents/nodes using different communication system/protocols.



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