CPS: Synergy: Resilient Wireless Sensor-Actuator Networks
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Project Objectives
Wireless sensor-actuator networks (WSANs) are systems consisting of numerous sensing and actuation devices that interact with the environment and coordinate their activities over a wireless communication network. WSANs represent an important class of cyber-physical system (CPS) found in our national civil infrastructure.

This project addresses the issue of resilience in WSANs. A resilient system is one that maintains an active awareness of surrounding threats and reacts to those threats in a manner that returns the system to operational normalcy in finite time. It has proven challenging to ensure resilience in large-scale WSANs because of the complexity such scale brings.

• The objective of this project is to develop WSANs that are resilient to faults in the underlying communication network. This will be done through the coordinated management of the WSANs control and communication functions. The methods will be evaluated on a multi-robotic testbed consisting of unmanned ground and aerial vehicles using machine-to-machine (M2M) communication technologies.

What is M2M Communication?
Wireless communication channels are inherently bursty. This burstiness can result in channel outages of relatively long duration. This project makes use of an exponentially bounded burstiness (EBB) model for channel outages. EBB channels bound the likelihood of long outages as an exponential function of the outage duration.

Traditional mean-square stability (MSS) is insufficient for safety-critical systems with bursty channels. This is because an MSS system may exhibit extremely large deviations away from equilibrium.

Almost Sure Stability of Networked Control Systems
Safety critical systems require the stronger notion of almost-sure stability. This means that that as time goes to infinity, the probability of a large state deviation goes to zero.

Resilient Cooperative Tasking
Besides leader-follower formation control, we also studied the resilient cooperative tasking for a group robots in uncertain and dynamic environments.

In particular, we aim to develop scalable and provably correct design method that can guarantee the accomplishment of high-level team missions through automatic synthesis of local coordination mechanisms and control laws.

The basic idea is to decompose the team mission into individual subtasks such that the design can be reduced to local synthesis problems for individual robots. Multidisciplinary approaches combining hybrid systems, supervisory control, regular inference and model checking are utilized to achieve this goal. The developed theory will enable teams in the leader to cooperatively learn their individual roles in a mission, and then automatically synthesize local supervisors to fulfill their subtasks.

This is different from most of existing approaches, such as swarming robotics, behavior based robotics, multi-agent system etc., which are bottom-up.

Noitre Dame Multi-Robot Testbed
The resilient control architecture and wireless networking technologies will be evaluated on an indoor multi-robot testbed consisting of a heterogeneous mobile robots communicating over an M2M wireless communication network. The testbed consists of both autonomous unmanned ground (UGVs) and aerial vehicles (UAVs) together with a 24-camera OptiTrack motion capture system that provides indoor localization information. The novelty in Notre Dame’s UAV/UGV testbed lies in its focus on multi-robot swarm resilience and its use of novel M2M communication technologies.

The UGV component consists of six ActivMedia Pioneer robots that use acoustic proximity sensors for collision avoidance, and a combination of gyro-corrected wheel encoders and laser rangefinder for localization and environment map building. The robots are equipped with a 2-DOF gripper with grasping pressure sensor, and are control-ed through an on-board PC that communicates to each other over an 802.11 wireless LAN card or M2M radio.

The UAV component consists of three quadrotors from Unmanned Dynamics, which are equipped with micro controllers, an analog 9-degree IMU, a pressure sensor and an onboard GPS module. To make these UAVs suitable for our research tasks, significant upgrades on their on-board sensor and processing capabilities have been carried out in my lab with the addition of wireless communication modules, upper-level processing board, on-board camera and vision processing. The quadrotor can both fly outdoor and indoor. We already tested outdoor autonomous flight using GPS modules to get position data. For indoor flight, we integrated the indoor localization module (Optirack) into the ground station that sends the position data to UAVs via 802.11 wireless LAN.

Our current efforts include equipping these UAVs with M2M wireless networking components to enable inter-vehicle communication and realizing the proposed resilient hybrid hierarchal controllers and top-down design theory.

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