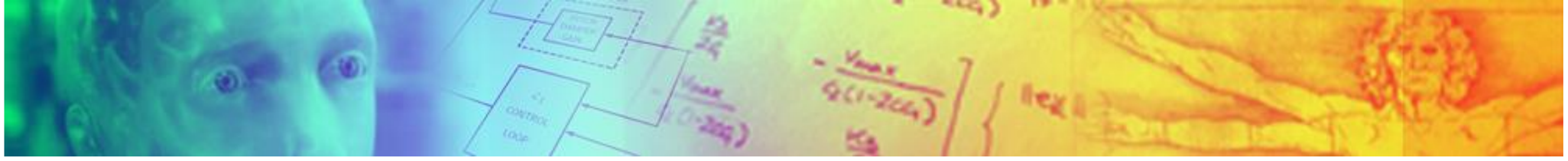


CONTROL ENGINEERING
DANCE
HUMAN FACTORS

ROBOTIC SYSTEMS
MUSIC
PSYCHOLOGY

What if Robots Could Tango?

Advanced Controls Research Laboratory, Department of Mechanical Science and Engineering, University of Illinois at Urbana-Champaign

Abstract

The coexistence of **robots and humans** is the vision of the not so distant future of **Cyber-Physical Systems** (CPS). In the CPS of tomorrow machines and computers will be our co-workers. They will speak and understand natural language, engage all our senses (touch, smell, etc.), understand what we want from the context, and adapt to our emotions.

In this perspective, it is our goal to design robots which are able to communicate continuously and bidirectionally with humans, feel their emotions, and perceive the surrounding environment. The robots of the new generation, equipped with a **Cyber Behavioral Adaptation** (CyBA) unit, must be able to take decisions (**improvise** and **lead**) based upon information received and perceived from the overall system, or comply with other's decisions (**follow**).

We propose an interdisciplinary approach to multi-agent robust CPS with real-time CyBA, which can be used as a schema to conduct research at the intersection of human factors, psychology, computer science, and robotic systems. This research will close a key gap by developing intelligent cyber-robotic systems that can deal with concurrent human skills and emotions and address the explicit implementation of emotional behavior interfaces to ensure that robots adapt to humans' current internal states.

Vision

How to bring CPS to the next level

- In social cooperative interactions, implicit emotional communication plays a crucial role. A robotic system that is capable of such affective communication with humans (operators, patients, etc.) and that can modify its behavior if required, will bring CPS to the next level.
- The benefits of robotic technologies can be drastically improved when machines can adapt their behaviors to the changes of humans' emotional states.
- Such benefits can be realized under realistic assumptions about automation capability and reliability.
- Robots must be given the possibility to improvise (safely) depending on humans and environmental changes.

Develop an integrated framework applicable to a broad class of multi-agent CPS

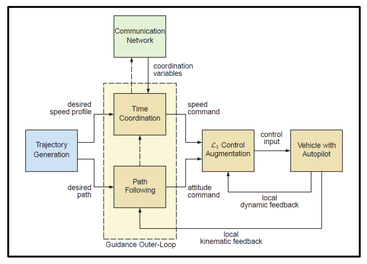
- Close presence of cooperative robots and humans
- Autonomous inspection of space systems
- Search/rescue missions
- Healthcare industry
- Intensive care units
- Robotic housekeeping

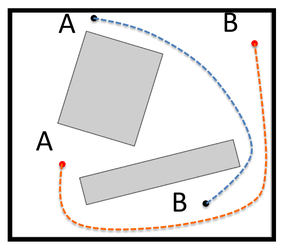
Development

- **Robust Robot Cooperative Motion Control**
- **Swarming Algorithms**
- **"Soft" vs "Hard" Collision (avoid, escape, perch, approach)**
- **CyBA (humans' emotions, level of skill, comfort zone)**
- **Structured Improvisation**
- **Illustrative Example – Humans-Robots dancing tango**
  - **Sense partners' awareness and comfort level with respect to their decisions and, if needed, adjust action**
  - **Sense if partners receive enough feedback and whether the actions correspond to the received invitations**
  - **Interpret the music, navigate the dance floor, avoid collisions, feel and direct the partners, take actions in relation to all these parameters**

Cooperative Motion Control

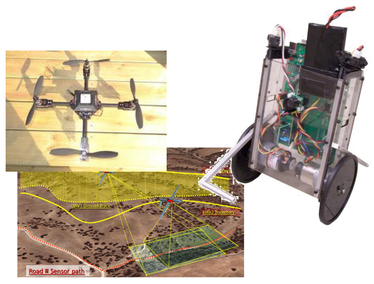
Previous Achievements
- Cooperative Trajectory Generation
- Path Following Control
- Time Coordination
- Collision Avoidance





Cooperative Trajectory Generation
- Dynamic constraints and minimum separation
- Inexpensive computation
- Synchronization

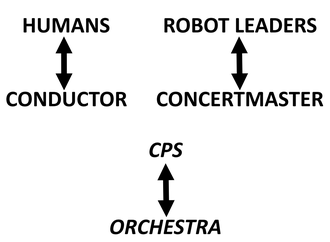
Path Following
- Multirotors
- Fixed-Wing UAVs
- Extension to ground robots and marine vehicles



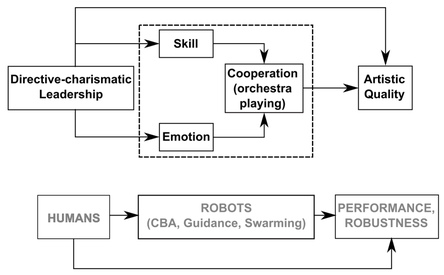
Time Coordination
- Faulty network and switching topologies
- General Solution (UAVs, ground robots, marine vehicles, etc.)
- Relative and Absolute Time Constraints

Swarming

When considering network of networks, the framework for cooperative control of multi-agents can be used to control the desired behavior of each team, and an higher-level swarming control algorithm has to be employed to control the network as a whole. At the local level of individual teams of vehicles, decentralized controls can be applied to achieve desired swarming behavior of the respective ensemble of vehicles.



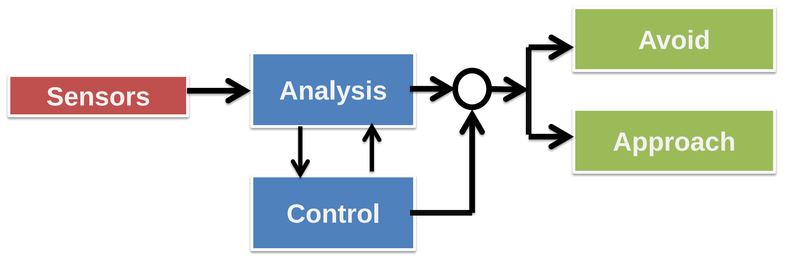
- The proposed **structure**, which resembles an Orchestra, allows **swarming** behavior of a fleet of multiple agents with minimal exchange of information
- Relevant in application such as autonomous spaceship and satellites



Model of leader behavior, follower behavior, and leadership success in the Symphony Orchestra and in the CPS

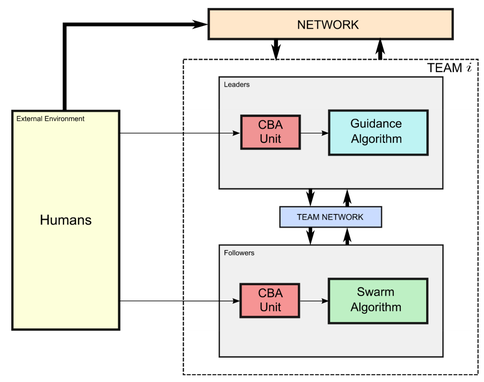
"Soft" vs "Hard" Collision

Humans and Robots can work closely (and safely)



- Collision avoidance algorithms based on velocity and position (minimize energy at impact)

Cyber Behavioral Adaptation (CyBA)



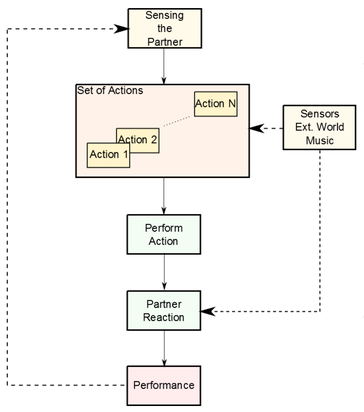
Tango as an example

-Study the effect of posture and dynamics on the perception of emotion and level of skills.

-By virtue of the **Cy**ber-**B**ehavioral **A**daptation (**CyBA**) unit, the robots perceive the **level of skills** and **emotions** of humans and adapt their **choreography** to improve safety and quality of the overall CPS.

-The **CyBA** Unit, combined with collision avoidance algorithms, ensure high levels of robustness of the CPS.

Structured Improvisation



- The robots of the new generation must be able to take decisions (**improvise** and **lead**) based upon information flows received and perceived from the overall system, or comply with others' decisions (**follow**).
- The set of skills of the robots is based on the learning algorithms.

What if Robots Could Tango?

A robot who is able to lead and follow its teammates/partners, feel their emotions, improvise, and cooperatively navigate in an human environment, is a robot who can definitely *tango.*

The cooperative robot-dancers will be capable of
- Sensing their partners/teammates awareness and comfort level with respect to their decisions so that they can, if needed, adjust their actions
- Sensing whether their partners receive enough feedback and whether their own actions correspond to the invitations they receive
- Interpreting the music (which can be seen as a low level command sent from a supervisor to the overall CPS), navigating the dancefloor to avoid collisions, feeling and directing the partner, and taking actions in relation to all these parameters