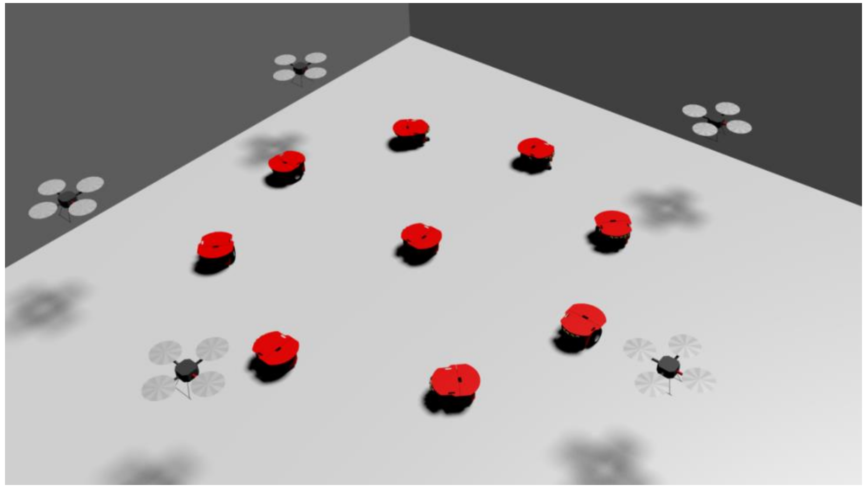
Human in the Loop – Network Control Systems



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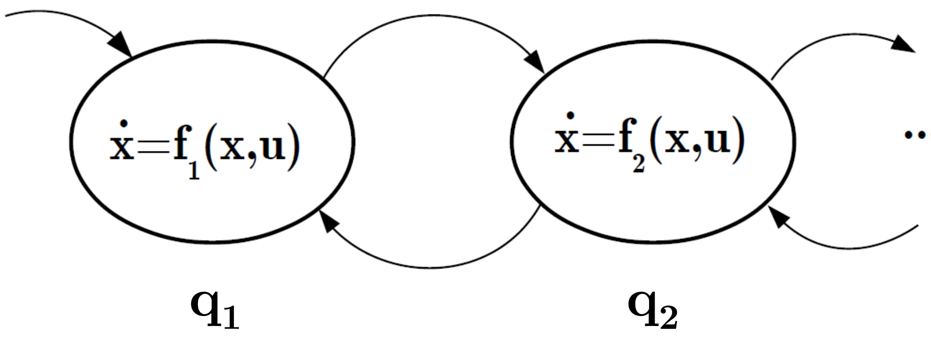
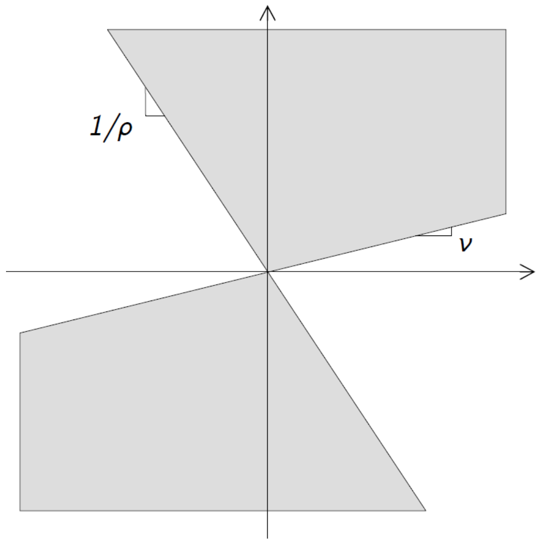
Prior research

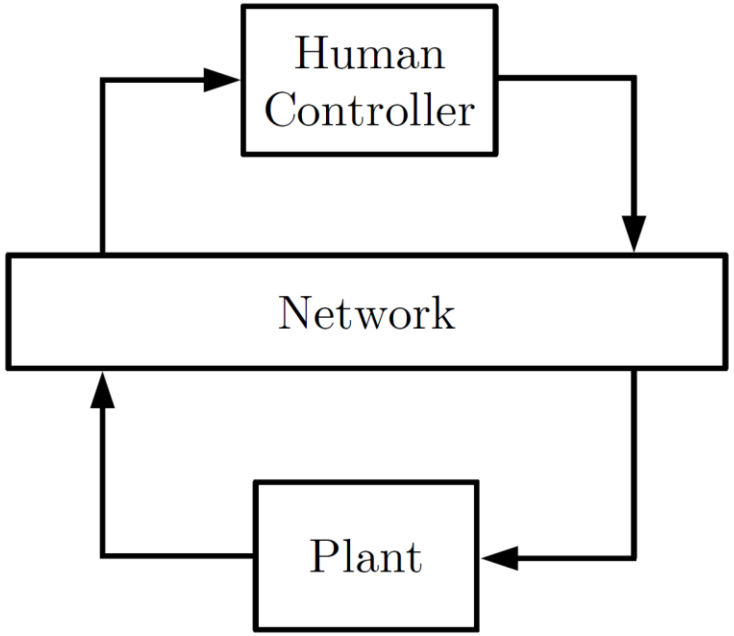
- **Nonlinear analysis of hybrid systems**
  - Passivity, dissipativity, conic systems
  - Hybrid systems: Switched systems, hybrid automata, discrete event systems



- **Network control systems**
  - Delays, dropped packets, quantization

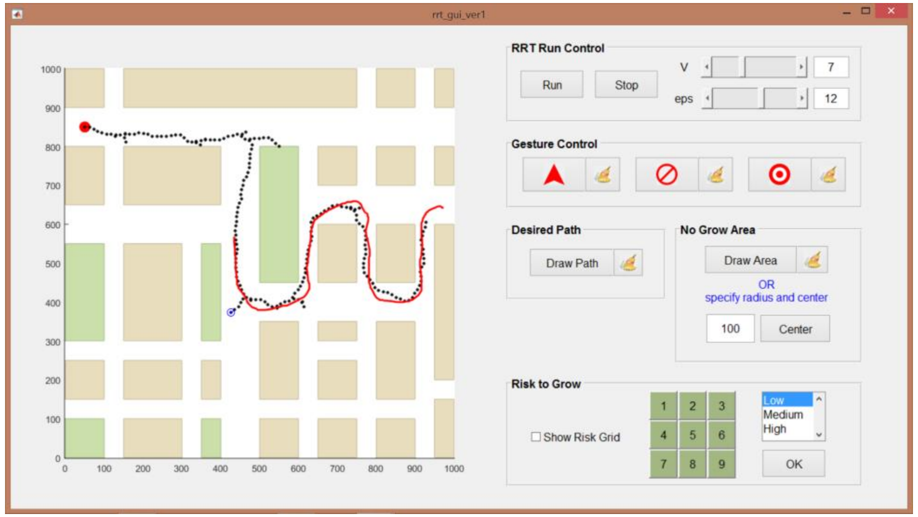
- **Motivated by…**
  - Cyber-physical-systems
  - Human-robotic systems
  - Telemanipulation systems
  - Human-in-the-loop control

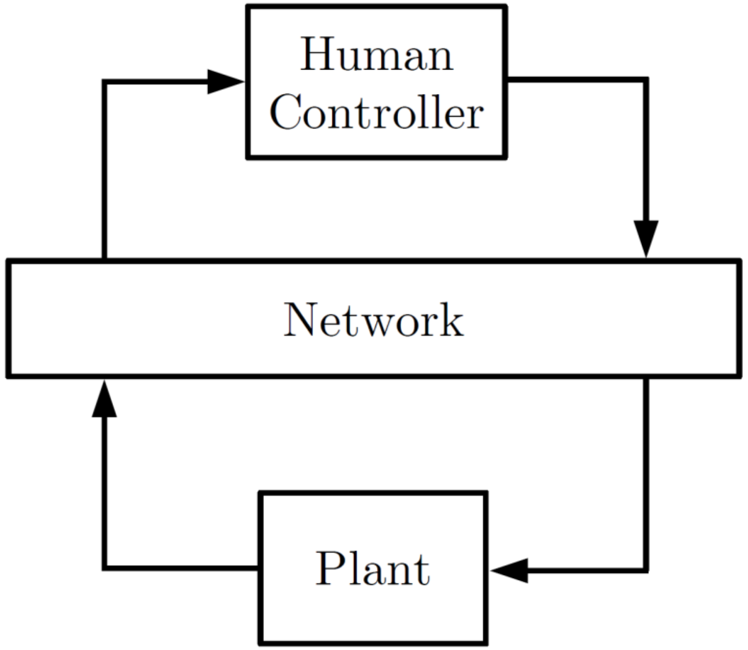


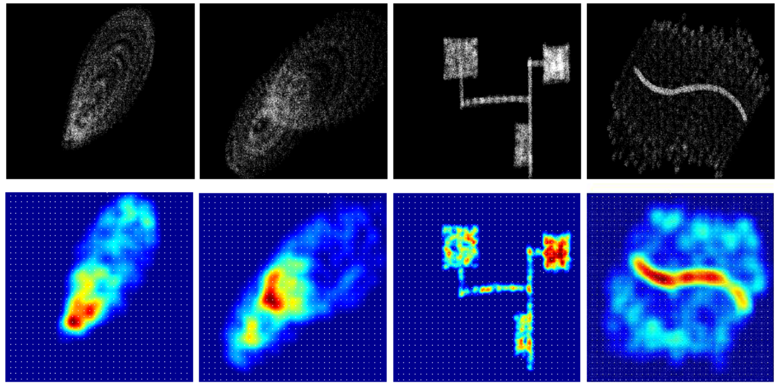


Ongoing research projects

- Human control implemented over networks
- Human-machine joint control
- Human-machine sensor fusion for estimation
- Adaptive randomized path planning
- Nonlinear/non-Gaussian estimation problems
- Estimation of team behavior
- Estimating human intent from EKG data

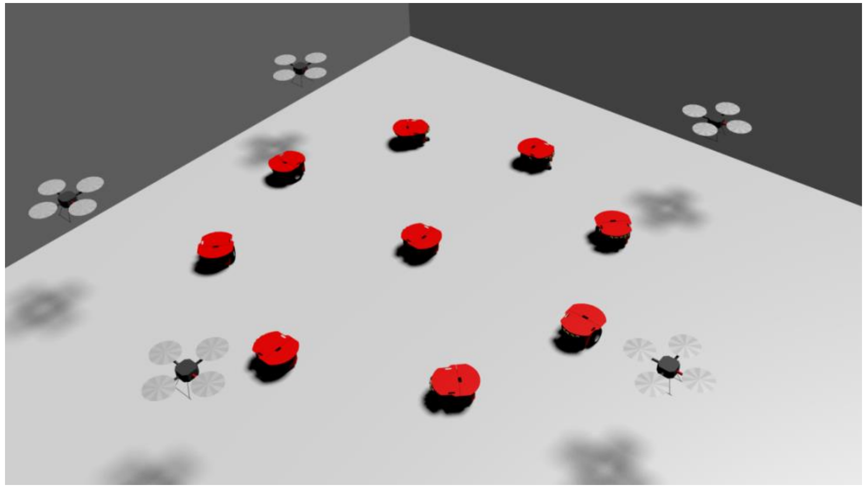




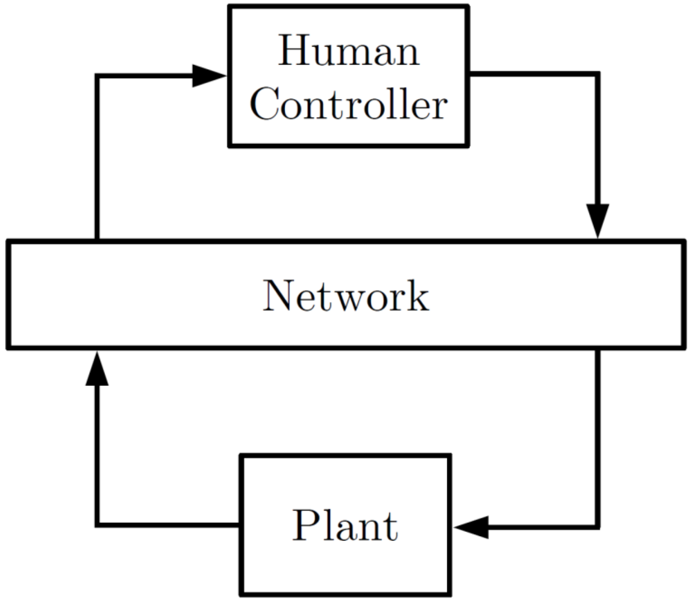


Estimation and control problems

- **Estimation of team behavior**
  - Teams can be autonomous agents, humans, or both
  - Information could be available or limited
  - Monitoring continuous states (position, velocity, etc.) as well as discrete behaviors (sensing, acting, group actions)



- **Human control over networks**
  - Human as a non-ideal controller
  - Potentially unstable plant
  - Network effects (delays, lost data, etc.)

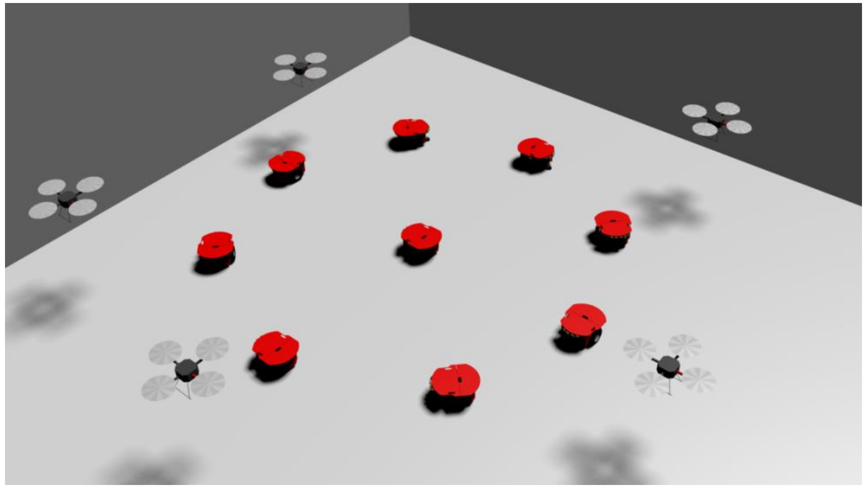


Motivation for team estimation

- **Monitor a team with limited information**
  - Could be self-reported information or observed
  - Make decisions based on agent states and behaviors
  - Better information fusion leads to better decision making

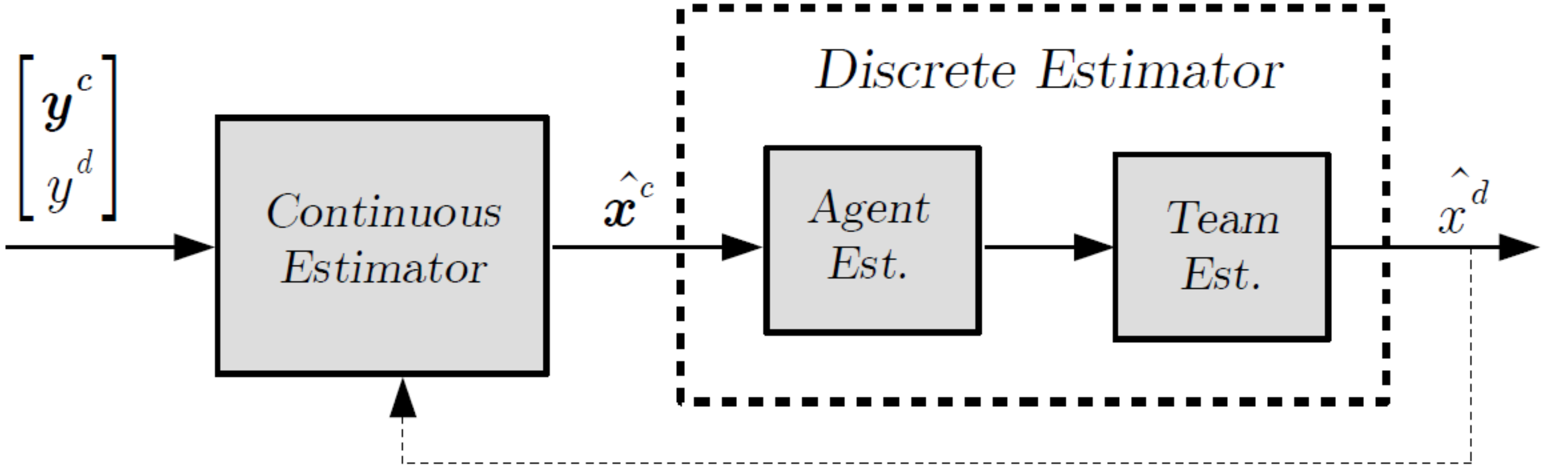
- **Interested in tracking…**
  - Continuous states: position, velocity, etc.
  - Discrete states: sensing, moving towards goal, interacting with the environment

- **Applications**
  - Network intrusion detection
  - Robotic soccer strategy
  - Economic strategy models



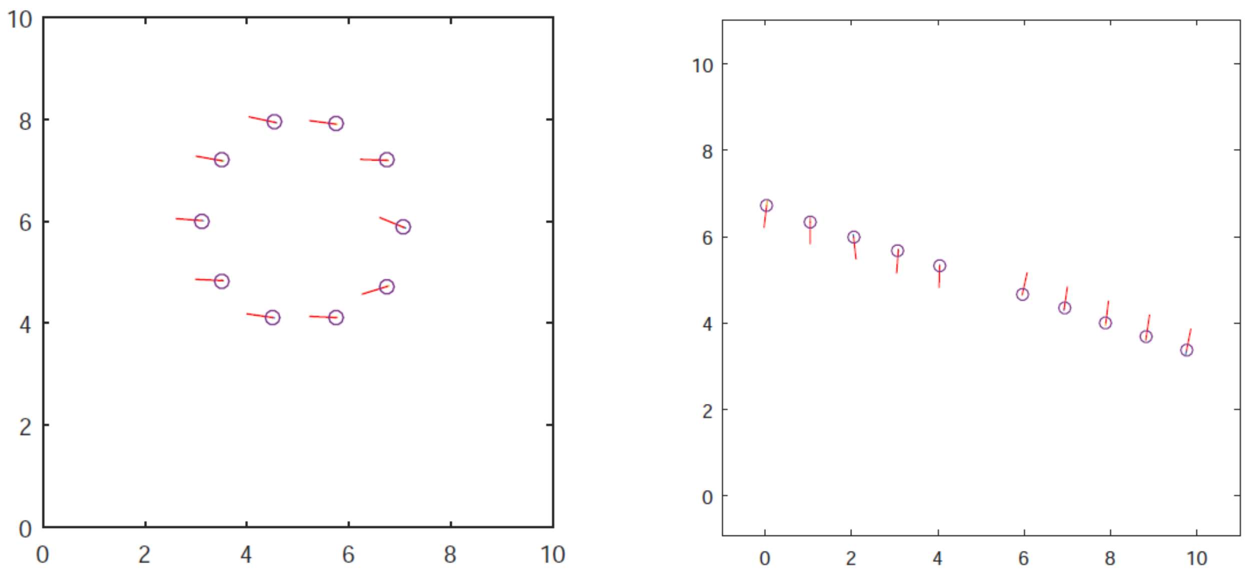
Hybrid system estimation approach

- **Estimation performed in stages**
  - Continuous states then discrete variables
- **Discrete estimator can be broken into two parts**
  - Individual agent actions considered before collective team behaviors
- **Under certain conditions can use discrete estimator to update the continuous estimator**



Application: Robotic vehicle formation identification

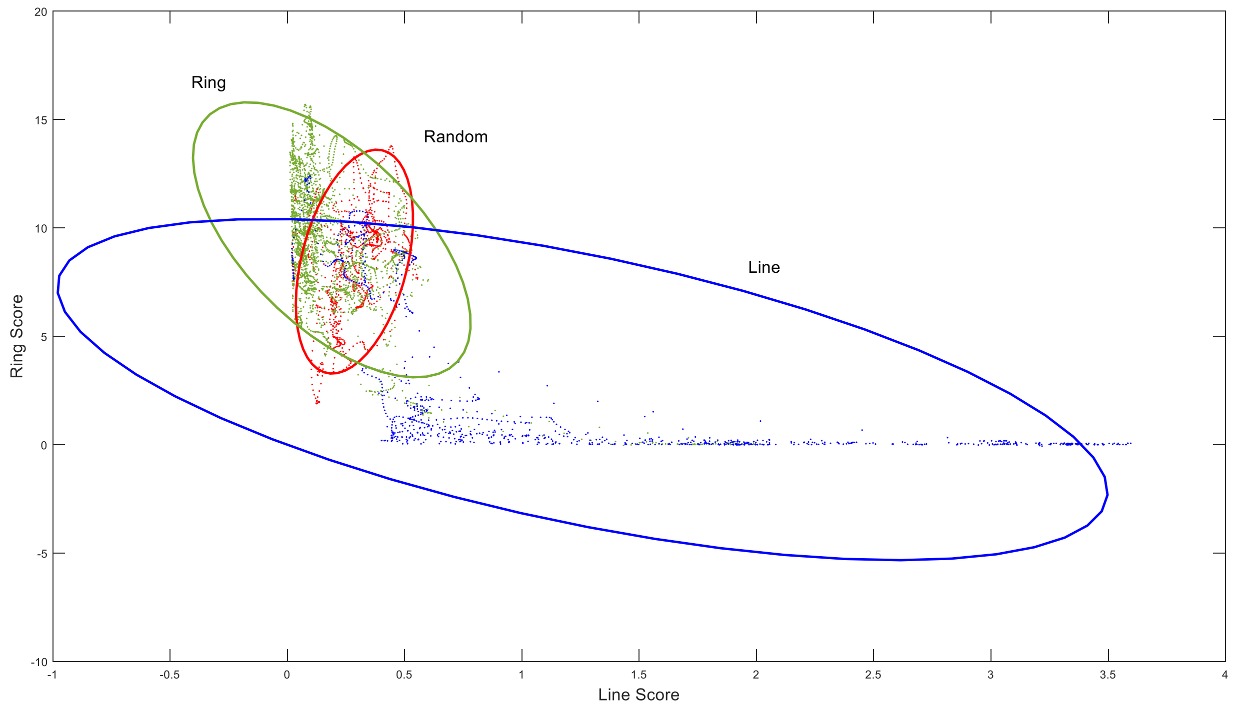
- **We applied this approach to estimating an opposing teams formation**
  - Ring, line, random motion
- **Incomplete information**
  - Can only sense a subset of the opponent agents (40-60%)
  - Measurements have Gaussian additive noise
- **Applied EKF for continuous state estimation**



(a) Ring formation (b) Line formation

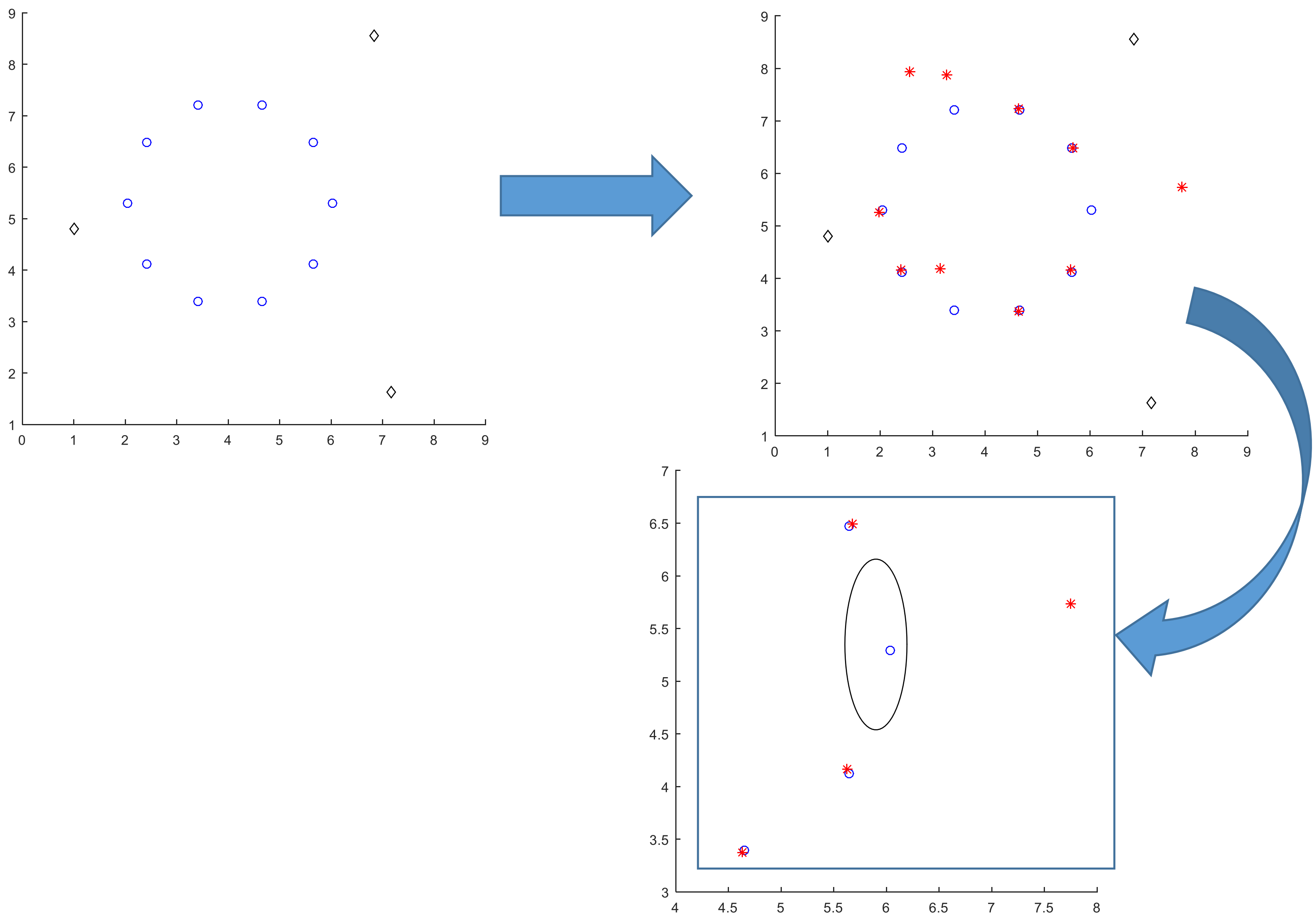
Discrete state estimation

- **Developed geometric rules for determining formation**
  - Score based on closeness to ring/line shape
- **Collected data on randomly generated formations**
  - Fit a Gaussian distribution based on noisy generated data
  - Naïve approach
- **Used this score to update discrete state of the team behavior**
  - Hidden Markov model (HMM)
  - Generate a likelihood of each state
  - At each step, belief changed using a Bayesian update law



Feedback mechanism for updating continuous estimator

- Can use knowledge of the discrete state to update the continuous states
- When discrete behavior is known with some confidence, can generate virtual measurements



Experimental validation

- Three graduate students implemented this as a summer project
- Five mobile robots, alternating between three discrete team states
- Results were promising but requires additional testing

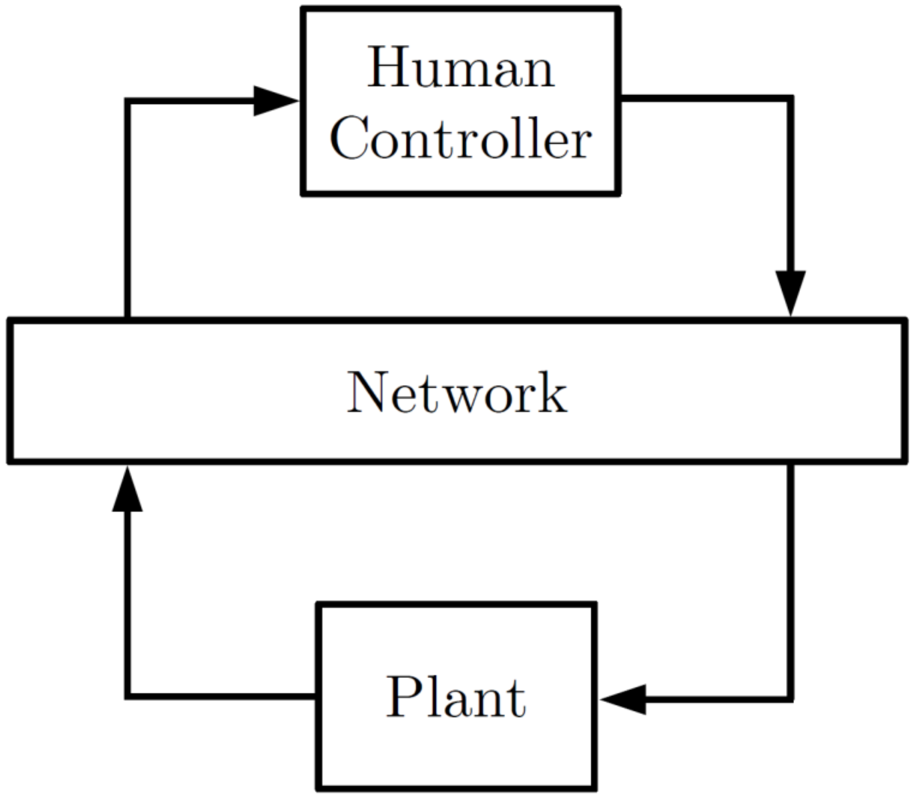
Human Control Over Networks

Human in the control loop

- **Assumptions…**
  - Nonlinear (possibly unstable) plant
  - Control over wireless network (delays, etc.)

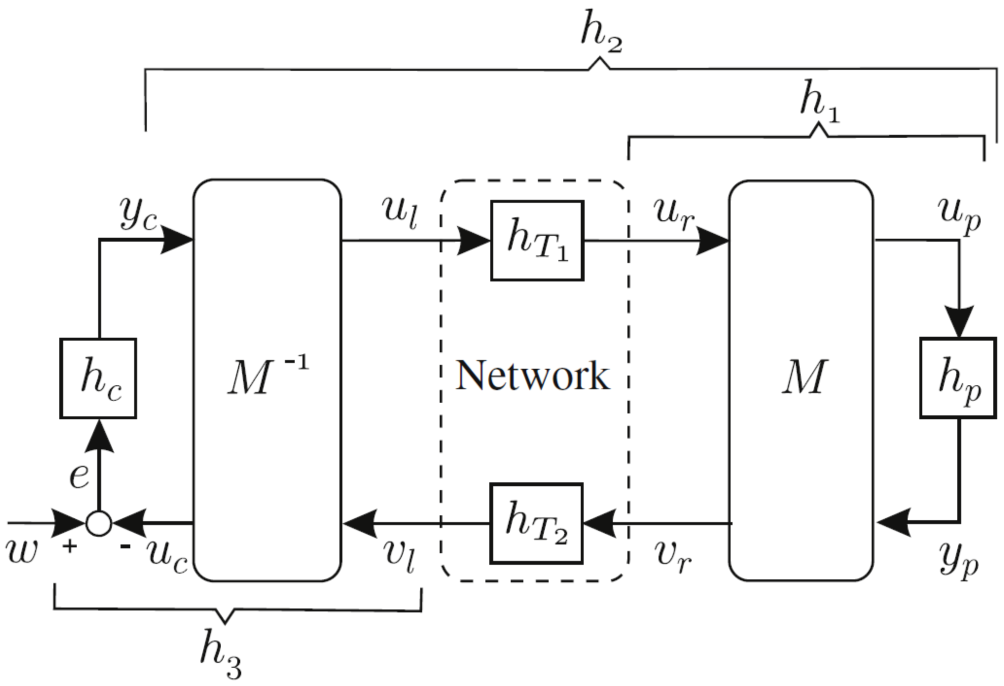
- **Classic nonlinear control approaches…**
  - Passivity
  - Dissipativity
  - Small gain theorem

- **These can’t be directly applied due to…**
  - Network delays
  - Unstable plant



Existing approaches for human-in-the-loop

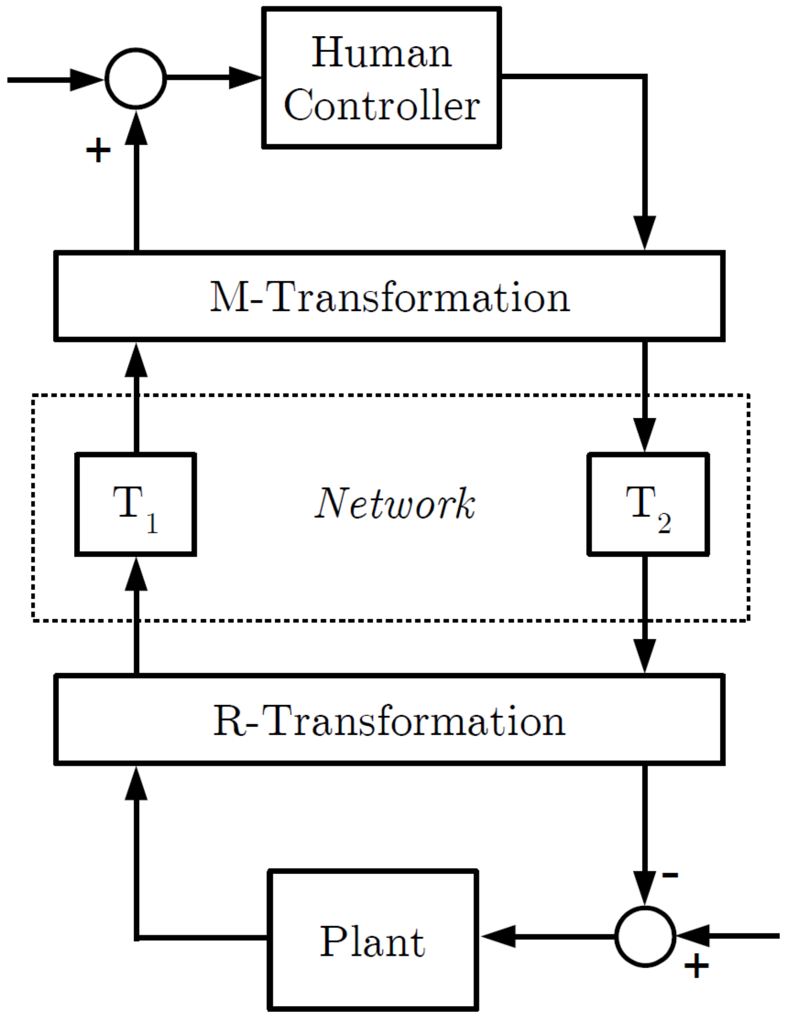
- **Telemanipulation or networked control**
  - Assumes the human is a passive system
- **"Network interface" to maintain stability despite network delay**
  - Wave variable transformation
  - Generalized network interface
- **Problem: Doesn't work for human in the loop**
  - Can't handle delays in the systems
  - Typical human reaction time delay is 200-500 ms



[Hirche, et al. 2009]

Solution – two new transforms

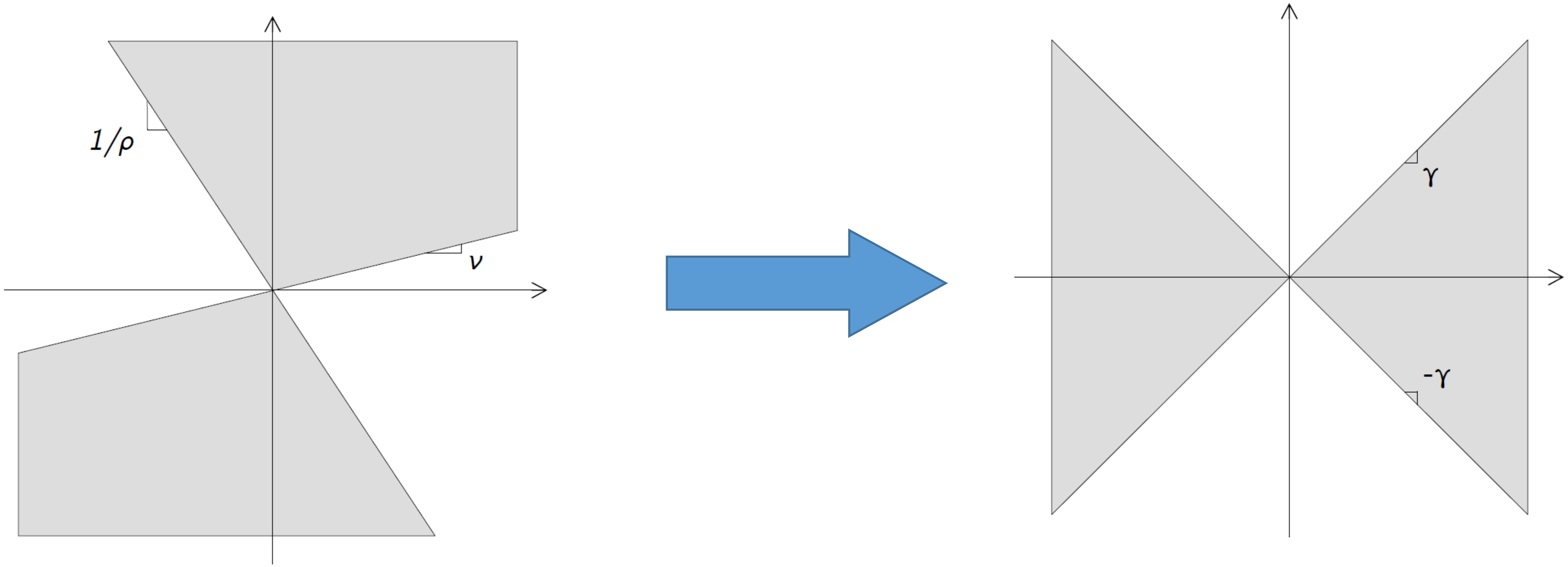
- **Transforms are implemented on each side of the network**
  - These can be used to **"pre-stabilize"** each side
- **On the human side, the transform scales down the response**
  - Slows system response
- **On the plant side, the transform rotates**
  - Based on conic system analysis
- **Stability results follow using the small gain theorem**



Plant transformation…

- **We are applying an input-output variable transformation**
  - Can be described as a rotation

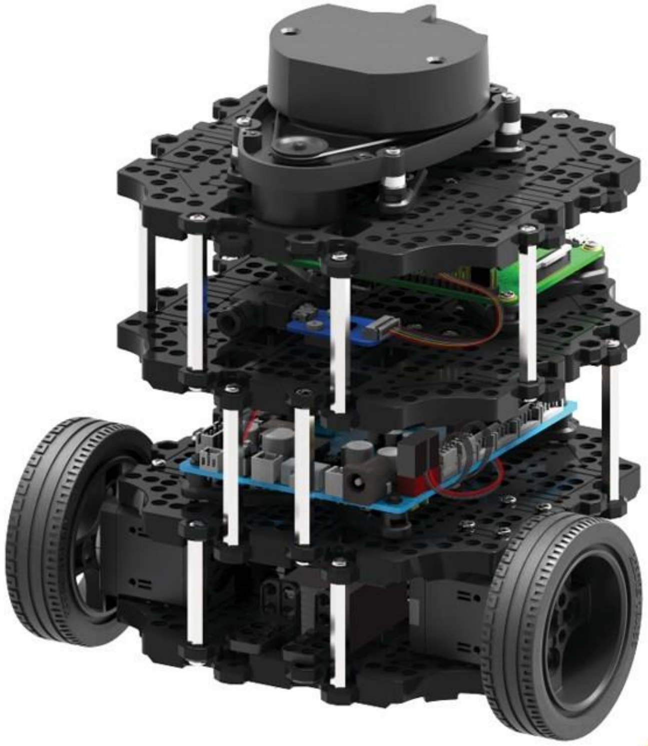
- **Can take an unstable conic system and rotate it to be stable**

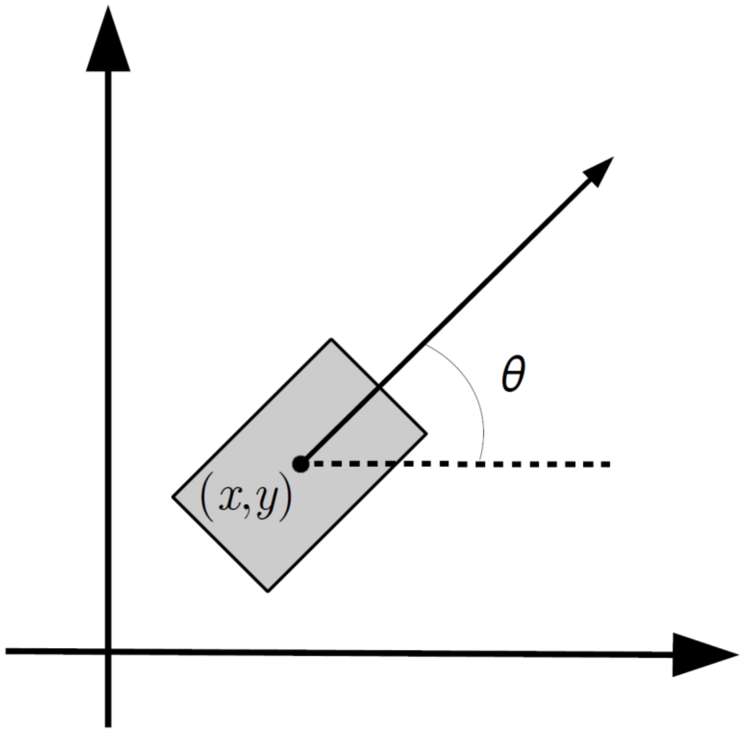


Applying this to human controlled vehicle experiments

- **Supervising undergraduate research applying this to ground robots**
  - Turtlebot 3
  - Wifi for network

- **The goal is to have a human controlled ground robot using wireless internet as a delayed network**





Thank you!