- UAS 16/6 (formation control (remaining) – i-o systems)
- Jam 1 pm-4 pm

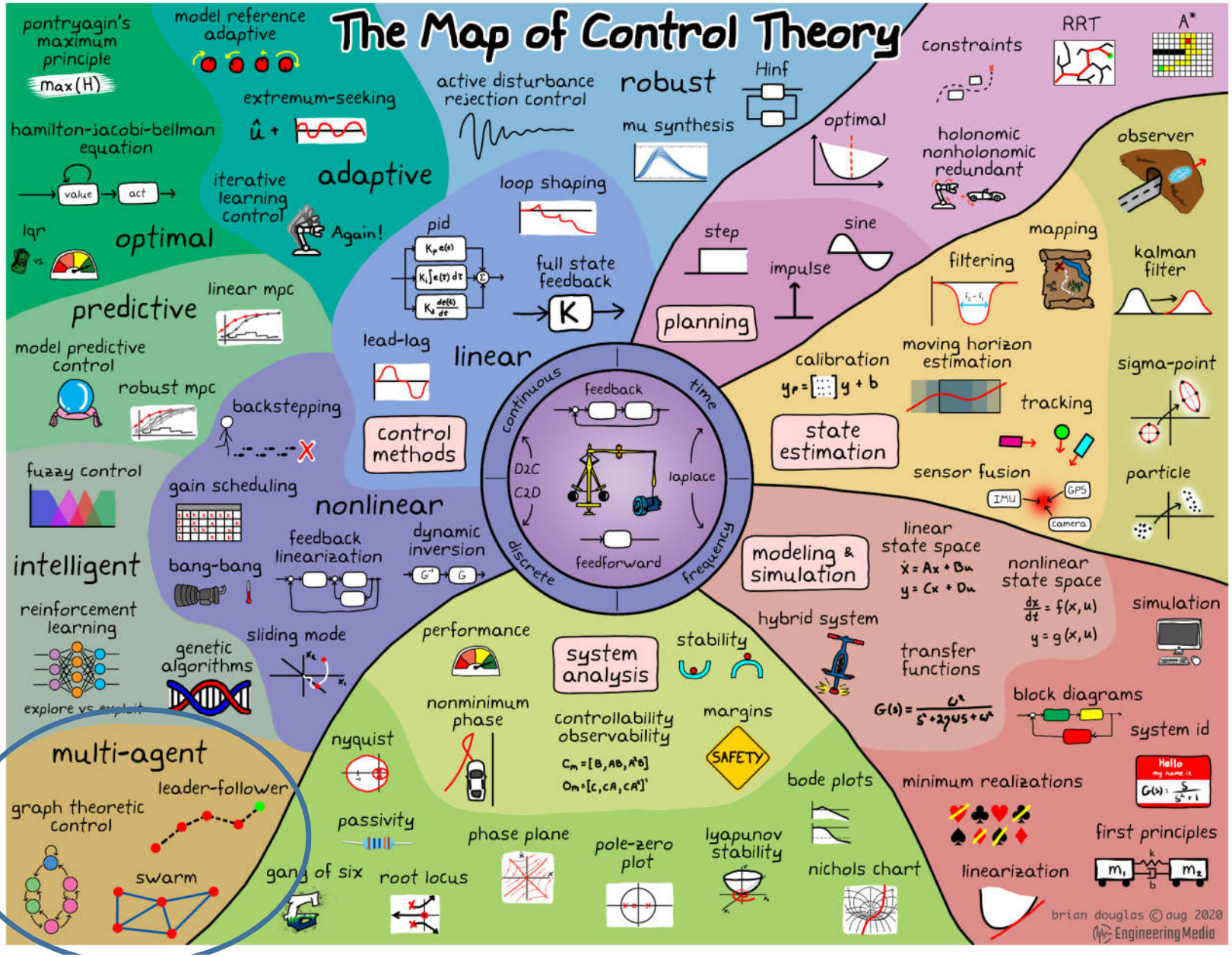
EE185523

# Review: Recent topics in formation control and multiagent systems

Yurid E. Nugraha
TSP DTE FTEIC ITS

# Recent topics in formation control and multiagent systems

- We will try to trace recent development of formation control, control over networks, and multiagent systems in general
- Disclaimer: The papers below will be *mostly* about the method rather than specific hardware/plant
- For time reason, the scope of topic is rather limited
- Discussion is highly encouraged


The Map of Control Theory
pontryagin's maximum principle
Max(H)
model reference adaptive
extremum-seeking
active disturbance rejection control
robust
Hinf
mu synthesis
constraints
RRT
A*
hamilton-jacobi-bellman equation
value
act
iterative learning control
adaptive
Again!
optimal
loop shaping
pid
full state feedback
K
lqr
vs
optimal
holonomic
nonholonomic
redundant
observer
step
sine
impulse
planning
mapping
filtering
kalman filter
linear mpc
predictive
model predictive control
robust mpc
lead-lag
linear
calibration
moving horizon estimation
sigma-point
backstepping
control methods
tracking
state estimation
fuzzy control
gain scheduling
nonlinear
sensor fusion
IMU
GPS
camera
particle
intelligent
feedback linearization
dynamic inversion
bang-bang
continuous
discrete
time
frequency
feedback
feedforward
laplace
D2C
C2D
modeling & simulation
linear state space
nonlinear state space
simulation
reinforcement learning
explore vs exploit
genetic algorithms
sliding mode
hybrid system
transfer functions
block diagrams
system id
performance
system analysis
stability
nonminimum phase
controllability
observability
margins
SAFETY
nyquist
bode plots
minimum realizations
multi-agent
leader-follower
graph theoretic control
swarm
passivity
phase plane
pole-zero plot
lyapunov stability
nichols chart
first principles
gang of six
root locus
linearization
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EngineeringMedia

# Robotarium?

## The Robotarium: A Remotely-Accessible, Multi-Robot Testbed for Control Research and Education

SEAN WILSON [1] AND MAGNUS EGERSTEDT [2] (Fellow, IEEE)

*(Tools Paper)*

[1]Georgia Institute of Technology, Atlanta, GA 30332 USA
[2]University of California, Irvine, Irvine, CA 92697 USA

CORRESPONDING AUTHOR: SEAN WILSON (email: sean.t.wilson@gatech.edu)

This work was supported in part by the U.S. National Science Foundation under Grants 1531195 and 1544332 and in part by the U.S. Office of Naval Research under Grant N00014-17-1-2323

**ABSTRACT** In robotic research and education, the cost in terms of money, expertise, and time required to instantiate and maintain robotic testbeds can prevent researchers and educators from including hardware based experimentation in their laboratories and classrooms. This results in robotic algorithms often being validated by low-fidelity simulation due to the complexity and computational demand required by high-fidelity simulators. Unfortunately, these simulation environments often neglect real world complexities, such as wheel slip, actuator dynamics, computation time, communication delays, and sensor noise. The Robotarium provides a solution to these problems by providing a state-of-the-art, multi-robot research facility to everyone around the world free of charge for academic and educational purposes. This paper discusses the remote usage of the testbed since its opening in 2017, details the testbeds design, and provides a brief tutorial on how to use it.

# Change of topic?

## Deterministic and Randomized Actuator Scheduling With Guaranteed Performance Bounds

**Publisher: IEEE** Cite This PDF

Milad Siami ; Alexander Olshevsky ; Ali Jadbabaie **All Authors**

**8** Paper Citations

**597** Full Text Views

**Abstract**

Document Sections

I. Introduction

II. Preliminaries and Definitions

**Abstract:**

In this article, we investigate the problem of actuator selection for linear dynamical systems. We develop a framework to design a sparse actuator schedule for a given large-scale linear system with guaranteed performance bounds using deterministic polynomial-time and randomized approximately linear-time algorithms. First, we introduce systemic controllability metrics for linear dynamical systems that are monotone and homogeneous with respect to the controllability Gramian. We show that several popular and widely used optimization criteria in the literature belong to this class of controllability metrics. Our main

# Still on consensus..

Automatica 141 (2022) 110308

Contents lists available at ScienceDirect

Automatica

journal homepage: www.elsevier.com/locate/automatica

Brief paper

## Cluster consensus on matrix-weighted switching networks☆

Lulu Pan [a,b,c], Haibin Shao [a,b,c,*], Mehran Mesbahi [d], Dewei Li [a,b,c], Yugeng Xi [a,b,c]

[a] Department of Automation, Shanghai Jiao Tong University, Shanghai, 200240, China
[b] Key Laboratory of System Control and Information Processing, Ministry of Education of China, Shanghai 200240, China
[c] Shanghai Engineering Research Center of Intelligent Control and Management, Shanghai, 200240, China
[d] William E. Boeing Department of Aeronautics and Astronautics, University of Washington, Seattle, WA, 98195-2400, USA

ARTICLE INFO

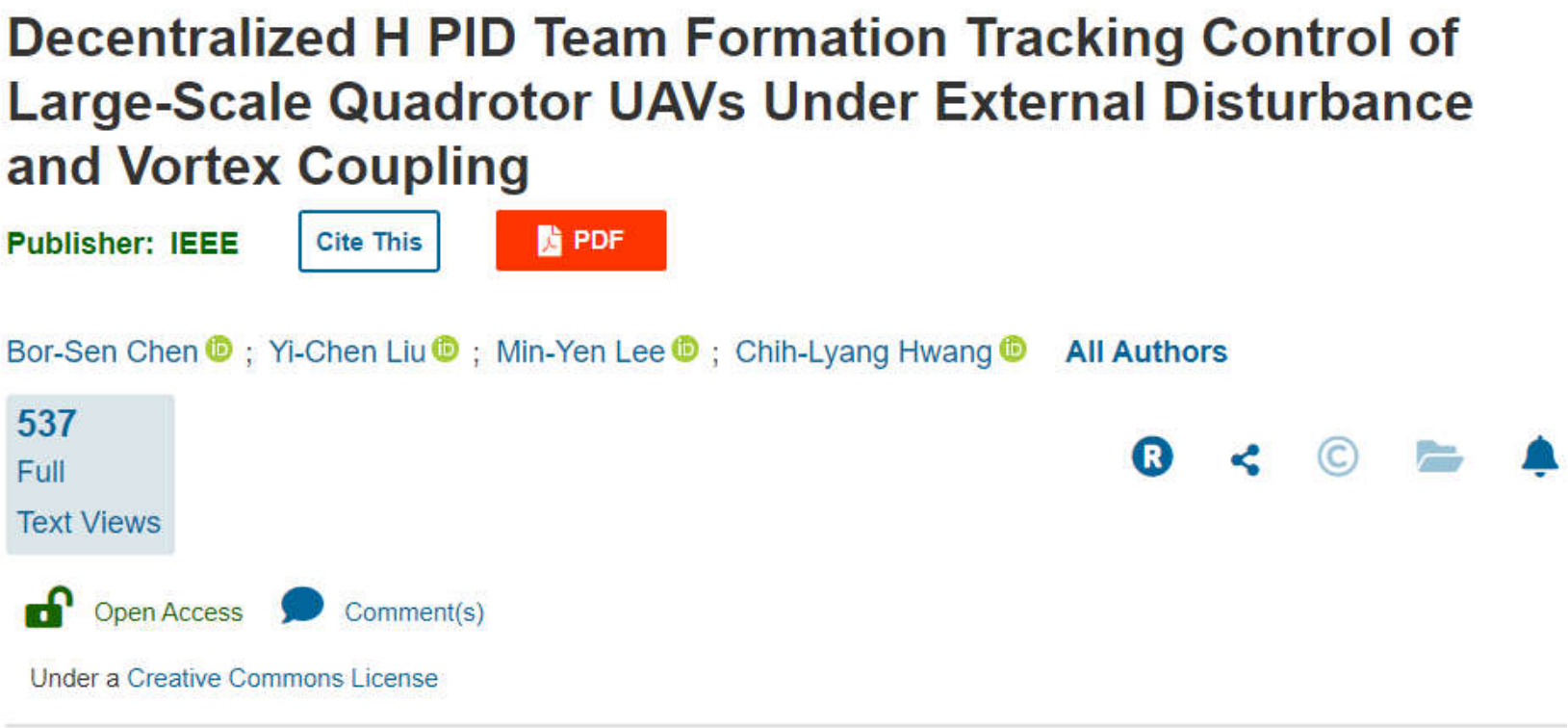
*Article history:*
Received 18 May 2021
Received in revised form 21 November 2021
Accepted 12 February 2022
Available online 26 April 2022

*Keywords:*
Cluster consensus
Matrix-weighted switching network
Integral network
Bipartite consensus

ABSTRACT

This paper examines cluster consensus for multi-agent systems on matrix-weighted switching networks. Necessary and/or sufficient conditions under which cluster consensus can be achieved are obtained, as well as quantitative characterization of the steady-state of the cluster consensus. Specifically, when the underlying network switches amongst a finite number of networks, a necessary condition for cluster consensus on matrix-weighted switching networks is derived; moreover, it is shown that the steady-state of the nodes lies at the intersection of the null spaces of the matrix-valued Laplacians of the corresponding switching networks. Furthermore, when the underlying network switches amongst an infinite number of networks, the matrix-weighted integral network is employed to provide sufficient conditions for cluster consensus; analogous to the previous case, the quantitative characterization of the corresponding steady-state of the nodes pertains to the null space analysis of matrix-valued Laplacian of the "integral" network. Lastly, conditions for bipartite consensus of matrix-weighted switching networks are provided. Simulation examples demonstrate the presented theoretical results.

# Quadrotor?



**Decentralized H PID Team Formation Tracking Control of Large-Scale Quadrotor UAVs Under External Disturbance and Vortex Coupling**

**Publisher: IEEE** Cite This PDF

Bor-Sen Chen ; Yi-Chen Liu ; Min-Yen Lee ; Chih-Lyang Hwang **All Authors**

537
Full
Text Views

Open Access Comment(s)

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**Abstract** **Abstract:**

# Robotics applications

Journals & Magazines > IEEE Transactions on Robotics > Volume: 39 Issue: 1

## Controlling Collision-Induced Aggregations in a Swarm of Micro Bristle Robots

Publisher: IEEE Cite This PDF

Zhijian Hao ; Siddharth Mayya ; Gennaro Notomista ; Seth Hutchinson ; Magnus Egerst... All Authors

744 Full Text Views

Abstract

**Abstract:**

Systematically designing local interaction rules to achieve collective behaviors in robot

# Heterogeneous agents



## Average-Consensus Tracking of Sensor Network via Distributed Coordination Control of Heterogeneous Multi-Agent Systems

Min Zheng, Cheng-Lin Liu, and Fei Liu

***Abstract*—Average-consensus tracking problem is investigated for sensor network, in which the computing units are modeled by heterogeneous multi-agent systems composed of first-order agents and second-order agents. To track the average value of sensors' measured values, the proportional-integral consensus tracking algorithms are proposed for first-order and second-order agents, respectively. By using generalized Nyquist stability criterion, sufficient conditions of average-consensus convergence are obtained for the heterogeneous multi-agent systems under a fixed, symmetric and connected topology. Furthermore, delay-dependent convergence conditions are obtained for the multi-agent systems with identical communication delay. Numerical simulations illustrate the correctness of our results.**

***Index Terms*—Sensor network, average-consensus**

systems, we use a heterogeneous multi-agent system of first-order agents and second-order agents to denote the computing units, respectively. Next, we mainly review the research results on the average-consensus tracking problem of multi-agent systems.

So far, consensus problem has been thoroughly studied for multi-agent systems under fixed topology, switching topologies, time delays, noises, etc [11], [12]. Specially, average-consensus problem requires that all the agents converge to the average value of agents' initial conditions [13], while average-consensus tracking problem means that each agent tracks the average value of all agents' given reference inputs. Olfati-Saber [7] proposed the distributed low-pass and high-pass consensus tracking algorithms, where each agent

# Consensus over the space

IEEE Access
Multidisciplinary | Rapid Review | Open Access Journal

Received 17 February 2023, accepted 5 March 2023, date of publication 5 April 2023, date of current version 14 April 2023.

*Digital Object Identifier 10.1109/ACCESS.2023.3264562*

RESEARCH ARTICLE

## Consensus Control of Multi-Hopping-Rover Systems: Convergence Analysis

**SHUNTARO TAKEKUMA[1], (Member, IEEE), SHUN-ICHI AZUMA[2], (Senior Member, IEEE), RYO ARIIZUMI[1], (Member, IEEE), AND TORU ASAI[1], (Member, IEEE)**

[1]Nagoya University, Nagoya, Aichi 464-8601, Japan
[2]Kyoto University, Kyoto 606-8501, Japan

Corresponding author: Shun-Ichi Azuma (azuma.shunichi.3e@kyoto-u.ac.jp)

This work was supported in part by JST FOREST Program under Grant JPMJFR2123; in part by JSPS KAKENHI under Grant JP21H04558; and in part by the Nagoya University Interdisciplinary Frontier Fellowship supported by Nagoya University and JST, the establishment of University Fellowships towards the Creation of Science Technology Innovation, under Grant JPMJFS2120.

**ABSTRACT** A *hopping rover* is a mobile robot developed for exploring low-gravity planets. The movement is based on *hopping* motion for moving on rough ground in low gravity. For efficient exploration, it is desirable to construct a cooperative system with multiple rovers. Such a system is called here the *multi-hopping-rover systems*. This paper addresses a *consensus control* problem for the multi-hopping-rover systems, where the hopping rovers involve uncertain dynamics caused by hopping motion. By representing

# Swarm Robots



## A Low-Complexity Brain–Computer Interface for High-Complexity Robot Swarm Control

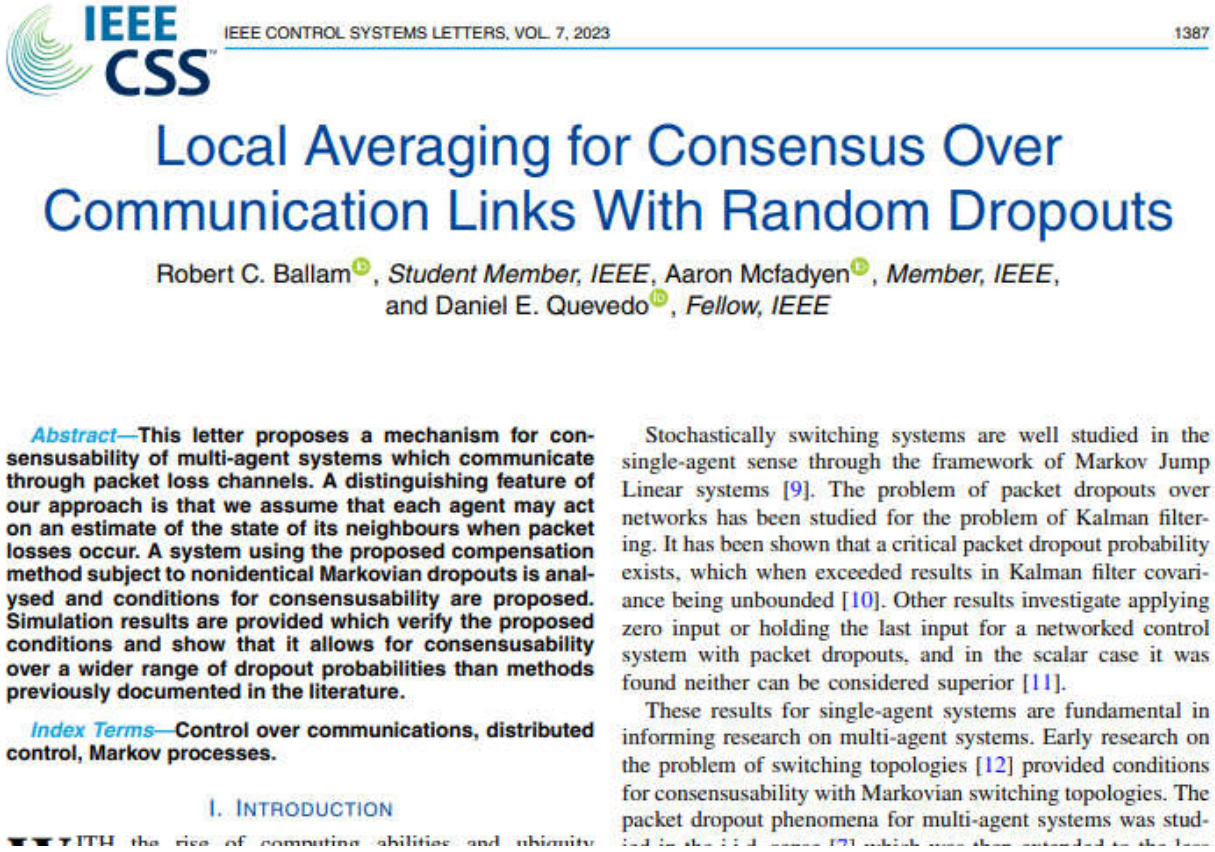
Gregory Canal, Yancy Diaz-Mercado, *Member, IEEE*, Magnus Egerstedt, *Fellow, IEEE*, and Christopher Rozell, *Senior Member, IEEE*

***Abstract*— A brain-computer interface (BCI) is a system that allows a human operator to use only mental commands in controlling end effectors that interact with the world around them. Such a system consists of a measurement device to record the human user's brain activity, which is then processed into commands that drive a system end effector. BCIs involve either invasive measurements which allow for high-complexity control but are generally infeasible, or noninvasive measurements which offer lower quality signals but are more practical to use. In general, BCI systems have not been developed that efficiently, robustly, and scalably perform high-complexity control while retaining the practicality of noninvasive measurements. Here we leverage recent results from feedback information theory to fill this gap by modeling BCIs as a communications system and deploying a human-implementable interaction algorithm for noninvasive control of a high-complexity robot swarm. We construct a scalable dictionary of robotic behaviors that can be searched simply and efficiently by a BCI user, as we demonstrate through a large-scale user study testing the feasibility of our interaction algorithm.**

### I. Introduction

BRAIN-computer interfaces (BCI) are systems that consist of hardware to measure a human user's brain activity, an interaction algorithm to map the user's mental commands to control signals, and an end effector that the user operates via these control signals. This direct link between brain and effector provides a means for paralyzed users to circumvent muscular pathways and interact with everyday devices [1] as well as an augmented interface for healthy users. There are several tradeoffs involved in the design of BCIs, including whether measurements are taken invasively or noninvasively, how many mental commands are needed to drive the effector to a desired behavior, how scalable the system is to effectors of varying complexity, and how robust the system is to user error and system noise in measurement processing. Although BCIs with invasive neural measurements have had experimental success in controlling high-complexity effectors (e.g., robotic

# Random graph (NCS)



IEEE CONTROL SYSTEMS LETTERS, VOL. 7, 2023 1387

## Local Averaging for Consensus Over Communication Links With Random Dropouts

Robert C. Ballam, *Student Member, IEEE*, Aaron Mcfadyen, *Member, IEEE*, and Daniel E. Quevedo, *Fellow, IEEE*

***Abstract*—This letter proposes a mechanism for consensusability of multi-agent systems which communicate through packet loss channels. A distinguishing feature of our approach is that we assume that each agent may act on an estimate of the state of its neighbours when packet losses occur. A system using the proposed compensation method subject to nonidentical Markovian dropouts is analysed and conditions for consensusability are proposed. Simulation results are provided which verify the proposed conditions and show that it allows for consensusability over a wider range of dropout probabilities than methods previously documented in the literature.**

***Index Terms*—Control over communications, distributed control, Markov processes.**

### I. Introduction

WITH the rise of computing abilities and ubiquity

Stochastically switching systems are well studied in the single-agent sense through the framework of Markov Jump Linear systems [9]. The problem of packet dropouts over networks has been studied for the problem of Kalman filtering. It has been shown that a critical packet dropout probability exists, which when exceeded results in Kalman filter covariance being unbounded [10]. Other results investigate applying zero input or holding the last input for a networked control system with packet dropouts, and in the scalar case it was found neither can be considered superior [11].

These results for single-agent systems are fundamental in informing research on multi-agent systems. Early research on the problem of switching topologies [12] provided conditions for consensusability with Markovian switching topologies. The packet dropout phenomena for multi-agent systems was stud-

# Noncooperative agents/robotics





## Short Papers

### Controlling Noncooperative Herds with Robotic Herders

Alyssa Pierson and Mac Schwager

***Abstract*—We present control strategies for robotic herders to drive noncooperative herds. Our key insight enforces geometrical relationships that map the combined dynamics to simple two-dimensional or three-dimensional nonholonomic vehicle models. We prove convergence of single-agent herds to a goal and propose strategies for multi-agent herds, verified in simulations and experiments.**

***Index Terms*—Biologically inspired robots, kinematics, mobile robots, multirobot systems, robotic herding.**

#### I. Introduction

We consider the problem of noncooperative herding, analogous to shepherding, wherein dogs drive a herd of sheep to a goal location. In this system, the "sheep" agents naturally run away from the "dog" robots. We design a feedback control strategy for the dogs to relocate the sheep to a goal region in the environment. The dogs coordinate their positions to partially encircle the herd, which steers the herd in a desired direction. To design these controllers, we show, under certain geometrical constraints, the dynamics of the system reduce to common nonholonomic vehicles in two-dimension (2-D) and three-dimension

dangers. In 3-D, this may include directing schools of fish or flocks of birds. In the case of an emergency evacuation, human crowds could be directed by robots using our control strategy. We consider this a noncooperative multirobot problem, since the objective of the dogs is to steer the sheep, but the sheep are not actively inclined nor opposed to being steered.

*Related Work:* There has been surprisingly limited prior work on noncooperative robotic herding. One exception is Vaughan's pioneering work [2], [3], in which a single robot is used to herd ducks. In Vaughan's work, the robot communicates with a centralized computer vision system to choose controllers to drive the herd to the goal. Lien *et al.* developed a set of behavior primitives for controlling a flock with multiple shepherds [4]. The herders are placed at a set of "steering points" around the flock, and choose their behavior primitive based on environmental properties. In [5], the authors use a sliding model controller to place herders around a single evader to drive that evader along a desired trajectory. The evader is repulsed from the herders with a linear force within some sensing range, otherwise does not react to the herders. In contrast, our work takes a control theoretic approach to

# Games over networks

## Coalitional Stochastic Differential Games for Networks

Publisher: IEEE Cite This PDF

Julian Barreiro-Gomez ; Quanyan Zhu All Authors

140
Full
Text Views

Abstract

Document Sections

I. Introduction

II. Preliminaries and

**Abstract:**

We consider a networked stochastic cooperative differential game by incorporating two types of networks that allow us to study both the dynamic coupling among decision-makers and their strategic interaction. We study a class of coalitional stochastic differential games by means of the Shapley value to determine how influential the edges of either the dynamic coupling or strategic interaction network are in the minimization of the common

# Games over networks

Journals & Magazines > IEEE Transactions on Control ... > Volume: 8 Issue: 1

**Dynamic Resilient Network Games With Applications to Multiagent Consensus**

**Publisher: IEEE** Cite This PDF

Yurid Nugraha ; Ahmet Cetinkaya ; Tomohisa Hayakawa ; Hideaki Ishii ; Quanyan Zhu **All Authors**

**11** Paper Citations

**741** Full Text Views

**Abstract**

**Abstract:**

A cyber security problem in a networked system formulated as a resilient graph problem

# Trending area

- Prominent researchers often work on trending but not yet established area
- Their papers often have rather strong theoretical background
- In Control, some top journals:
  - IEEE TAC, IEEE TCNS, IEEE TNSE, IEEE L-CSS, IEEE T.Robotics, Automatica, etc.
- Some top conferences: CDC, ACC, ECC, ICRA, IROS

# Trending area

- https://css.paperplaza.net/conferences/conferences/CDC22/program/CDC22_KeywordIndexWeb.html
- https://ifac.papercept.net/conferences/conferences/IFAC23/program/IFAC23_KeywordIndexWeb.html
- Etc.