

María Santos

POSTDOCTORAL RESEARCH ASSOCIATE · Robot Swarms · Collective Intelligence
Princeton University · H-116 Engineering Quadrangle, Princeton, NJ 08544

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Research Focus

Multi-Robot Learning Distributed estimation and learning for multi-robot exploration

Heterogeneous Swarms Decision making and task allocation in robot teams with heterogeneous capabilities

Robotic Art Expressive motion in robotic swarms, design of human swarm interaction strategies

Education

Georgia Institute of Technology

Atlanta, GA, USA

PHD IN ELECTRICAL AND COMPUTER ENGINEERING

Aug. 2016 - Jul. 2020

- Thesis: *Coverage Control: From Heterogeneous Robot Teams to Expressive Swarms*
- Cumulative GPA: 4.0/4.0

MASTER OF SCIENCE IN ELECTRICAL AND COMPUTER ENGINEERING

Aug. 2014 - May 2016

- Thesis: *Musical Abstractions for Multi-Robot Coordination*
- Cumulative GPA: 4.0/4.0

Universidade de Vigo

Vigo, Spain

MASTER IN ADVANCED INDUSTRIAL PROCESSES AND TECHNOLOGIES

Oct. 2013 - Jul. 2014

- Thesis: *Obstacle Avoidance System in 3D Based on CVM*
- Cumulative GPA: 9.18/10.00

INDUSTRIAL ENGINEERING, SPECIALIZATION IN AUTOMATIC CONTROL AND ELECTRONICS

Sep. 2008 - Sep. 2013

- Thesis: *Adaptation of RIDE Environment Tools to the ROS Architecture*
- 5 year engineering degree equivalent to BSc and MSc
- Cumulative GPA: 8.67/10.00 (*Most Outstanding Graduate Award*)

Conservatorio de Música Manuel Quiroga

Pontevedra, Spain

PROFESSIONAL DEGREE IN MUSIC, SPECIALIZATION IN VIOLIN

Sep. 2005 - Jun. 2012

- Cumulative GPA: 8.60/10.00

Experience

Princeton University

POSTDOCTORAL RESEARCHER (SUPERVISOR: NAOMI EHRICH LEONARD)

Oct. 2020 - present

- Developed **statistical models** for multi-agent teams **to learn unknown tasks and optimize their execution**. Designed algorithms where the multi-agent task is modeled as Gaussian processes that can be solved in a decentralized way
- Worked on decentralized **decision making** strategies that use **game theory** and **nonlinear opinion dynamics** for multi-agent task allocation and inter-agent coordination. Multi-agent coordination (agreement/disagreement over options) is proved analytically using bifurcation theory
- Deployment of algorithms for multi-robot path planning and decision making (using **Python, MATLAB, ROS**) on robotic platforms (TurtleBot with OpenMANIPULATOR-X, Clearpath Jackal), motion capture system (Vicon)
- **Technical advisor** of 4 graduate students and co-advisor of 7 undergraduate students
- Co-organizer of the ICRA 2023 **Workshop on Multi-Robot Learning**

Georgia Institute of Technology

GRADUATE RESEARCH ASSISTANT (PH.D. ADVISOR: MAGNUS EGERSTEDT)

Aug. 2016 - Jul. 2020

- Designed mathematical models to capture the complexities of **heterogeneous agents** with different equipment/capabilities. Built a **decentralized optimization** method whereby the heterogeneous team fulfills multiple tasks by executing heterogeneous gradient descent strategies
- Developed algorithms for multi-agent teams to **optimize time-varying objectives** in a decentralized fashion. Each agent minimizes its control action solving a quadratic programming problem where tasks are synthesized as constraints
- Designed **human-swarm interaction** strategies to command dynamic objectives to multi-agent teams in real time
- **Technical advisor** of 2 visiting international students and advisor of 1 undergraduate student

Universidade de Vigo

RESEARCH ASSISTANT (ADVISOR: JOAQUÍN LÓPEZ FERNÁNDEZ)

Oct. 2012 - Jul. 2014

- Developed libraries for **task allocation and scheduling** (ROS, Java) and obstacle avoidance (C) for a robotics development framework

Teaching Experience

Lecturer

Princeton University

MODERN CONTROL, MAE 434

Spring 2022

- Undergraduate/graduate course on state-space methods for robust **control design and analysis of dynamical systems**. Topics included stability analysis (Lyapunov and input-output), controllability, feedback control, state estimation, and optimal and robust control design methods (LQR, MPC)

Teaching Staff

Coursera

CONTROL OF MOBILE ROBOTS

Feb. 2019 - Aug. 2020

- MOOC on the application of modern control theory to control mobile robots
- Responsibilities: updating course materials, moderating discussion forums

Graduate Teaching Assistant & Guest Lecturer

Georgia Institute of Technology

OPTIMAL CONTROL AND OPTIMIZATION, ECE 6553

Spring 2017

- Undergraduate/graduate course on **advanced topics in programming methods**, data management, distributed computing, and advanced algorithms used in typical engineering applications (C & C++)
- Responsibilities: lecturing, holding office hours, co-designing homework, grading (97 on-campus and 25 off-campus students)

Graduate Teaching Assistant

Georgia Institute of Technology

ADVANCED PROGRAMMING TECHNIQUES, ECE 4122/6122

Fall 2015

- Undergraduate/graduate course on advanced topics in programming methods, data management, distributed computing, and advanced algorithms used in typical engineering applications (C & C++)
- Responsibilities: holding office hours, grading (200 on-campus students)

Students Supervised

2022 - 2023 Caroline Hana (Princeton ECE '23), Senior Thesis

Doing the Robot: Application of Opinion Dynamics for Collective Motion on the Rhythm Bots Art Installation

2021 - 2022 Ken Nakamura (Princeton MAE '23), Junior Independent Work

Decentralized Multi-Robot Estimation and Coverage of Spatial Fields

2021 - 2022 Ritika Ramprasad (Princeton ECE '22), Senior Thesis

Designing and Implementing Strategies for Human-Robot Interaction Using a Nonlinear Model of Opinion Dynamics

2021 - 2022 Sarah Witzman (Princeton MAE '22), Junior Independent Work and Senior Thesis

Design of Robotic Mechanism for Rhythm Bots Art Installation (Awarded the Morgan W. McKinzie '93 Senior Thesis Prize)

2021 - 2022 Christine Ohenzuwa (Princeton MAE '23), Junior Independent Work
Spatial Decision Making via Nonlinear Opinion Dynamics

2020 - 2021 Stella Fournier (Georgia Tech ECE '23), President's Undergraduate Research Award
Design of a Spray Painting BrushBot for Swarm Artistic Painting

Publications

JOURNAL PUBLICATIONS

- [J6] A. Bizyaeva, G. Amorim, **M. Santos**, A. Franci and N. E. Leonard, "Switching transformations for decentralized control of opinion patterns in signed networks: application to dynamic task allocation", *IEEE Control Systems Letters*, June 2022.
- [J5] S. Kim, **M. Santos**, L. Guerrero-Bonilla, A. Yezzi, and M. Egerstedt. "Coverage Control of Mobile Robots With Different Maximum Speeds for Time-Sensitive Applications", *IEEE Robotics and Automation Letters*, vol. 7, no. 2, pp. 3001-3007, April 2022.
- [J4] **M. Santos**, G. Notomista, S. Mayya, and M. Egerstedt. "Interactive Multi-Robot Painting Through Colored Motion Trails" *Frontiers in Robotics and AI, Robotic Control Systems*, Vol. 7, 143, 2020.
- [J3] **M. Santos** and M. Egerstedt. "From Motions to Emotions: Can the Fundamental Emotions Be Expressed in a Robot Swarm?" *International Journal of Social Robotics*, July 2020.
- [J2] **M. Santos**, Y. Diaz-Mercado and M. Egerstedt, "Coverage Control for Multirobot Teams With Heterogeneous Sensing Capabilities." *IEEE Robotics and Automation Letters*, vol. 3, no. 2, pp. 919-925, April 2018.
- [J1] J. López, D. Pérez, **M. Santos** and M. Cacho. "GuideBot. A Tour Guide System Based on Mobile Robots." *International Journal of Advanced Robotic Systems*, 10:381, November 2013.

CONFERENCE PUBLICATIONS

- [C10] C. Cathcart, **M. Santos**, S. Park, N. E. Leonard. "Proactive Opinion-Driven Robot Navigation around Human Movers". *IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, 2023 (accepted).
- [C9] K. Nakamura*, **M. Santos***, and N. E. Leonard. "Decentralized Learning With Limited Communications for Multi-robot Coverage of Unknown Spatial Fields". *IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, Kyoto, Japan, Oct. 2022, pp. 9980-9986. (*Equal contribution.)
- [C8] **M. Santos**, U. Madhushani, A. Benevento, and N. E. Leonard. "Multi-robot Learning and Coverage of Unknown Spatial Fields". *IEEE International Symposium on Multi-robot and Multi-agent Systems (MRS)*, Cambridge, UK, November 2021, pp. 137-145.
- [C7] A. Benevento, **M. Santos**, G. Notarstefano, K. Paynabar, M. Bloch, and M. Egerstedt. "Multi-Robot Coordination for Estimation and Coverage of Unknown Spatial Fields". *IEEE International Conference on Robotics and Automation (ICRA)*, Paris, France, May 2020, pp. 7740-7746.
- [C6] R. Funada, **M. Santos**, T. Gencho, J. Yamauchi, M. Fujita, and M. Egerstedt. "Visual Coverage Maintenance for Quadcopters Using Nonsmooth Barrier Functions". *IEEE International Conference on Robotics and Automation (ICRA)*, Paris, France, May 2020, pp. 3255-3261.
- [C5] G. Notomista, S. Mayya, M. Selvaggio, **M. Santos**, and C. Secchi. "A set-theoretic approach to multi-task execution and prioritization". *IEEE International Conference on Robotics and Automation (ICRA)*, Paris, France, May 2020, pp. 9873-9879.
- [C4] **M. Santos**, S. Mayya, G. Notomista, and M. Egerstedt. "Decentralized Minimum Energy Coverage Control for Time-Varying Density Functions". *IEEE International Symposium on Multi-robot and Multi-agent Systems (MRS)*, New Brunswick, NJ, August 2019. **Outstanding paper finalist.**
- [C3] G. Notomista, **M. Santos**, S. Hutchinson, and M. Egerstedt. "Sensor Coverage Control Using Robots Constrained to a Curve". *IEEE International Conference on Robotics and Automation (ICRA)*, Montreal, May 2019, pp. 3010-3016.
- [C2] R. Funada, **M. Santos**, J. Yamauchi, T. Hatanaka, M. Fujita, and M. Egerstedt. "Visual Coverage Control for Teams of Quadcopters via Control Barrier Functions". *IEEE International Conference on Robotics and Automation (ICRA)*, Montreal, May 2019, pp. 3010-3016.

- [C1] **M. Santos** and M. Egerstedt. “Coverage Control for Multi-Robot Teams with Heterogeneous Sensing Capabilities Using Limited Communications”. in *IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, Madrid, October 2018, pp. 5313-5319.

WORKSHOP PAPERS

- [W2] **M. Santos**, U. Madhushani, A. Benevento, and N. E. Leonard. “Multi-robot Learning and Coverage of Unknown Spatial Fields”. *ARMS-2022: AAMAS Workshop on Autonomous Robots and Multi-Robot Systems*, Auckland, New Zealand, May 2022.
- [W1] **M. Santos** and M. Egerstedt. “From Motions to Emotions: Exploring the Emotional Expressiveness of Robot Swarms”. *ICRA-X: Robotic Art Program*, Montréal, May 2019.

THESES

- [T4] **M. T. Santos Fernández**. *Coverage Control: From Heterogeneous Robot Teams to Expressive Swarms*. PhD Thesis, School of Electrical and Computer Engineering, Georgia Institute of Technology, July 2020.
- [T3] **M. T. Santos Fernández**. *Musical Abstractions for Multi-Robot Coordination*. Master’s Thesis, School of Electrical and Computer Engineering, Georgia Institute of Technology, April 2016.
- [T2] **M. T. Santos Fernández**. *Sistema de Evitación de Obstáculos en 3D Basado en CVM (3D Obstacle Avoidance System Based on CVM)*. Master’s Thesis, School of Industrial Engineering, University of Vigo, July 2014.
- [T1] **M. T. Santos Fernández**. *Adaptación de Herramientas del Entorno RIDE para su Utilización en la Arquitectura ROS (Adaptation of RIDE Environment Tools to the ROS Architecture)*. Proyecto Final de Carrera (Final Engineering Degree Project), School of Industrial Engineering, University of Vigo, September 2013.

Invited Talks

University of Illinois Urbana-Champaign

ROBOTICS SEMINAR @ ILLINOIS

March 2023

West Virginia University

WEST VIRGINIA UNIVERSITY ROBOTICS SEMINAR SERIES

July 2022

IEEE Robotics & Automation Society

WOMAN IN ROBOTICS AND CONTROL SEMINAR SERIES

December 2021

FSU-FAMU College of Engineering

DEPARTMENT OF MECHANICAL ENGINEERING SEMINAR SERIES

November 2020

University of Pennsylvania

GRASP LAB, MULTI-ROBOT SYSTEMS GROUP

September 2019

Georgia Institute of Technology

ROBOTICS STUDENT SEMINAR SERIES

September 2018

Art Exhibits

Rhythm Bots

LEWIS CENTER FOR THE ARTS, PRINCETON, NJ, USA

May 2023

PINK NOISE PROJECTS GALLERY, PHILADELPHIA, PA, USA

May 2022

- Artists: Naomi Ehrich Leonard, Susan Marshall, María Santos, Caroline Hana, Sarah Witzman, Isla Xi Han, and Kathryn Wantlin.
- Featured in the *ICRA 2022 Robotics and Art: Automating Expressions*.

Service

Organizer

2023 INTERNATIONAL CONFERENCE ON ROBOTICS AND AUTOMATION (ICRA) WORKSHOP: MULTI-ROBOT LEARNING

Co-organized with Profs. Amanda Prorok, Javier Alonso-Mora, and Mac Schwager

2021 AMERICAN CONTROL CONFERENCE SPECIAL SESSION: "DIVERSITY AND MENTORSHIP"

Panel with Profs. Martha Grover, Rafael Fierro and Andrew G. Alleyne.

Reviewer

JOURNALS

Transactions on Robotics (T-RO), Robotics and Automation Letters (RA-L), Autonomous Robots (AURO), Transactions on Automatic Control (TAC), Transactions on Control of Network Systems (TCNS), Control Systems Letters (L-CSS)

CONFERENCE PROCEEDINGS

International Conference on Robotics and Automation (ICRA), International Conference on Intelligent Robots and Systems (IROS), International Symposium on Multi-Robot and Multi-Agent Systems (MRS), Robotics: Science and Systems (RSS), Annual Learning for Dynamics and Control Conference (L4DC)

Scholarships & Awards

Aug. 2017 - **La Caixa Scholarship for Graduate Studies in North-America**

Aug. 2019 Awarded by Obra Social La Caixa

Oct. 2015 **Premio Fin de Carrera, Xunta de Galicia**

Awarded to the most outstanding Industrial Engineer graduating in the academic year 2013-14 in Galicia, Spain

Jan. 2015 **Premio Fin de Carrera, Universidade de Vigo**

Awarded to the most outstanding Industrial Engineer graduating in 2013-14 at the University of Vigo

Aug. 2014 - **Fulbright Scholarship for Graduate Studies**

May 2016 Awarded by the Fulbright Commission in Spain

Media Coverage

[M7] **TECHnically Creative with María Santos**, *TECHnically Creative: Georgia Tech Alumni and the Arts, Facebook Live interview*, January 2021.

[M6] **Robot swarms guided by human artists could paint colourful pictures**, *New Scientist*, October 2020.

Tiny robots create art and other tech news stories, *BBC News*.

Researchers train robot swarm to serve as 'real-life paintbrushes', *ZME Science*.

In the near future, robot swarms guided by human artists could execute paintings, *Designboom*.

Robots might take over this essential human form of expression, *Inverse*.

Robot swarms follow instructions to create art, *TechXplore, Robohub, Medium, Frontiers Science News, Nanowerk News*.

Tiny robots work together to paint pictures, *New Atlas*.

Scientists program robot swarms to create art, *UPI*.

New system helps control swarm of robots to paint a picture, *AZoRobotics*.

Roboter-Schwarm als Pinsel-Ersatz in der Kunst (Robot Swarm as a Replacement for Brushes in Art), *Heise Online*.

Ein Roboterschwarm wird kreativ (A robotic swarm gets creative), *Scinexx - Das Wissensmagazin*.

Desarrollan enjambres de robots que podrán pintar cuadros a partir de música (Researchers develop robotic swarms which will be able to render paintings from music), *La Voz de Galicia*.

Sciame di robot diventano pittori (Swarms of robots become painters), *Agenzia Nazionale Stampa Associata (ANSA)*.

Sciame di robot guidati da artisti umani per creare composizioni pittoriche (Robotic swarms led by human artists to create pictorial compositions), *Affari Italiani*.

[M5] **From motion to emotion: The potential of robot swarms in artistic performances**, *TechXplore*, April 2019.

[M4] **Gallegos en la Cima. María Santos Fernández: "EEUU te anima a salir de lo común y me ha permitido fusionar robótica y música"** (Galicians on Top. María Santos Fernández: "USA encourages you to think outside the box and has allowed me to mix robotics and music"), *Faro de Vigo*, March 2018.

[M3] **Santos Chosen for La Caixa Fellowship**, *Georgia Tech News Center*, June 2017.

La violinista que investiga sobre robótica (The violinist that is also a robotics researcher), *La Voz de Galicia*, June 2017.

La caldense María Teresa Santos, becada por "La Caixa" (María Santos receives a "La Caixa" Fellowship), *Faro de Vigo*, June 2017.

Una caldense ampliará estudios en EE.UU. tras lograr una beca "La Caixa" (A woman from Caldas will further her studies in the US after been awarded a "La Caixa" Fellowship), *La Voz de Galicia*, May 2017.

[M2] **Women of Robotics**, *Georgia Tech News Center*, April 2017.

[M1] **Una mente prodigiosa para idear robots en Georgia** (A prodigious mind to conceive robots in Georgia), *La Voz de Galicia*, April 2014.

Outreach

Promotion of STEM disciplines to primary, middle and high school girls

IES AQUIS CELENIS – INTERNATIONAL DAY OF WOMEN AND GIRLS IN SCIENCE EVENT
IC SANTA LUCIA – CURVATURA SCIENTIFICA
CEIP ALBORADA – INTERNATIONAL DAY OF WOMEN AND GIRLS IN SCIENCE EVENT
IES MEAÑO – INTERNATIONAL DAY OF WOMEN AND GIRLS IN SCIENCE EVENT
ATLANTA GIRLS' SCHOOL – MAKE HER DAY

Caldas de Reis, Galicia, Spain – Feb. 2022
Bergamo, Lombardia, Italy – Dec. 2021
A Coruña, Galicia, Spain – Feb. 2021
Meaño, Galicia, Spain – Feb. 2020
Atlanta, GA, USA – Apr. 2019

Mentoring

INTERNATIONAL MENTORING FOUNDATION FOR THE ADVANCEMENT OF HIGHER EDUCATION (IMFAHE)
Career mentoring for Spanish master's and Ph.D. students

Oct 2016 - Jul 2018