María Santos

POSTDOCTORAL RESEARCH ASSOCIATE · *Robot Swarms* · *Collective Intelligence*

Princeton University · *H-116 Engineering Quadrangle, Princeton, NJ 08544*

✉ maria.santos@princeton.edu | ⌂ mariasantos.me

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

Professional Appointments

Princeton University   *Princeton, NJ, USA*

Postdoctoral Researcher (P.I.: Naomi Ehrich Leonard) and Lecturer   *Oct. 2020 - present*

- Currently working 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 using bifurcation theory
- Developed mathematical models for multi-agent teams to optimize over unknown tasks. Designed an algorithm where the task is described as an optimization problem that can be solved in a decentralized way by the agents and where the task is learned as a Gaussian process
- Technical advisor of 5 graduate students and co-advisor of 6 undergraduate students
- Development on robotic platforms (TurtleBots with OpenMANIPULATOR-X, Clearpath Jackals), motion capture system (Vicon). Management of laboratory repositories (Python, C++, ROS)

Georgia Institute of Technology
Atlanta, GA, USA

GRADUATE RESEARCH ASSISTANT (ADVISOR: MAGNUS EGERSTEDT) — Aug. 2016 - Jul. 2020

MASTER'S STUDENT — Jan. 2015 - May 2016

- Designed mathematical models to capture the complexities of heterogeneous agents with different equipment/capabilities. Built a decentralized optimization method that distributes the heterogeneous multi-agent team over multiple tasks. Optimization techniques comprised heterogeneous gradient descent strategies
- Developed algorithms for multi-agent teams to optimize time-varying objectives in a decentralized fashion. Each agent minimized its control effort solving for a minimum-energy problem where objectives where 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
Vigo, Spain

GRADUATE RESEARCH ASSISTANT (ADVISOR: JOAQUÍN LÓPEZ FERNÁNDEZ) — Oct. 2013 - Jul. 2014

UNDERGRADUATE RESEARCH ASSISTANT — Oct. 2012 - Jul. 2013

- 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 modern state-space methods for robust control system design and analysis. Topics include stability, controllability and observability, feedback control and optimal and robust control design methods

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

- Graduate course on optimal control of dynamic systems, numerical optimization techniques and their applications in solving optimal-trajectory problems
- Responsibilities: lecturing, holding office hours, co-designing homework, grading (97 on-campus students and 25 off-campus)

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 - present Caroline Hana (Princeton ECE '23), Senior Thesis
Collective Strategies for Rhythm Bots coordination

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

[C9] K. Nakamura*, **M. Santos***, and N. E. Leonard. "Voronoi-based Learning of Spatial Fields for Multi-robot Coverage". *IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, 2022, *accepted*.

[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 Quad-copters 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*, Aukland, 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

Multirobot Coordination for Exploration Missions and Artistic Applications *Morgantown, WV, USA*
West Virginia University *July 2022*
West Virginia University Robotics Seminar Series

Coverage Control for Robotic Swarms: Heterogeneity, Learning, and Artistic Expression *Online Event*
IEEE Robotics & Automation Society *December 2021*
Women in Robotics and Control Seminar Series

Robotic Swarms: From Heterogeneity to Artistic Expression *Tallahassee, FL, USA*
FSU-FAMU College of Engineering *November 2020*
Department of Mechanical Engineering Seminar Series

University of Pennsylvania: GRASP Lab, Multi-robot Systems Group *September 2019*
Coverage Control: From Heterogeneous Robot Teams to Expressive Swarms

Georgia Institute of Technology: Robotics Student Seminar Series *September 2018*
Coverage Control for Multi-Robot Teams with Heterogeneous Sensing Capabilities

Art Exhibits

Rhythm Bots   *Philadelphia, PA, USA*

PINK NOISE PROJECTS GALLERY   *May 2022*

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

Professional Service

Organizer

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

Panel with Profs. Martha Grover, Rafael Fierro and Andrew G. Alleyne on the relationship between diversity and mentorship and the beneficial impact one may have on the other.

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)

Scholarships & Awards

Aug. 2017 - Aug. 2019	**La Caixa Scholarship for Graduate Studies in North-America** 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 - May 2016	**Fulbright Scholarship for Graduate Studies** 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 coud 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*.

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

Sciami 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 studios 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	*Caldas de Reis, Galicia, Spain – Feb. 2022*
IC Santa Lucia – Curvatura Scientifica	*Bergamo, Lobardia, Italy – Dec. 2021*
CEIP Alborada – International Day of Women and Girls in Science Event	*A Coruña, Galicia, Spain – Feb. 2021*
IES Meaño – International Day of Women and Girls in Science Event	*Meaño, Galicia, Spain – Feb. 2020*
Atlanta Girls' School – MAKE Her Day	*Atlanta, GA, USA – Apr. 2019*

Mentoring

International Mentoring Foundation for the Advancement of Higher Education (IMFAHE)	*Oct 2016 - Jul 2018*

Career mentoring for Spanish master's and Ph.D. students