Dr. Sathyanarayan Rao

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Research Scientist & Digital Twin Developer

Indian Institute of Science, Bengaluru

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Education

- **PhD in Engineering Sciences**, UCLouvain, Belgium   2016 – 2020
  Thesis: Computational Modeling of Electrical Signatures of Plant Roots
  Advisor: Prof. Mathieu Javaux

- **MS in Optical Physics**, Alabama A&M University, USA   2013 – 2014
  GPA: 4.0/4.0

- **MS in Electrical Engineering**, University of Alabama in Huntsville, USA   2010 – 2012
  GPA: 3.9/4.0   Advisor: Prof. Nagendra Singh

- **B.Eng in Electronics and Communication**, VTU, India   2006 – 2010
  First Class with Distinction

Research Experience

- **Research Associate**, Indian Institute of Science, Department of Civil Engineering   April 2025 – Present
  - Developing interactive dashboards for visualization and analysis of high-resolution hydrological and agricultural time series datasets.
  - Applying advanced time series analysis techniques including cross-correlation, LSTM neural networks, seasonal decomposition, and anomaly detection.
  - Investigating crop-wise variability in Leaf Area Index (LAI) and employing random forest regression to model satellite backscatter-soil moisture relationships.
  - Supervising undergraduate student research and designing scientific exercises for educational purposes.
  - Preparing comprehensive dataset paper combining multidisciplinary approaches in hydrology and agriculture.

- **Research Software Engineer**, Phenorob Project, Forschungszentrum Jülich   2023 – 2025
  - Developed interfaces to enable coupling between one-dimensional crop models (C++) and plant-scale Functional-Structural Plant Models (FSPM, Fortran), implementing advanced loose coupling techniques and addressing time synchronization challenges.
  - Authored comprehensive review paper on crop model coupling methods for agricultural digital twin applications.
  - Independently developed project website www.phenorobdaa.de from scratch using Hugo, HTML, and CSS.
  - Deployed large scale simulations on high-performance computing clusters using models like TSMP and Terrsys-MP.
  - Created scientific animations to visualize complex soil-plant interface processes for research

communication.

\- Led monthly project coordination meetings and contributed to book chapters on Role of Large Language models and UAV drones in agriculture.

- **Research Associate**, Indian Institute of Science, Bengaluru   2022 − 2023
  \- Developed machine learning models, particularly LSTM networks, for soil moisture estimation using satellite backscatter data, combining data-driven modeling with ground-truth validation.
  \- Coordinated bi-weekly field campaigns to local watershed sites, synchronizing measurements with satellite overpasses for accurate ground-truth data collection and validation.
  \- Trained research team members in field protocols and instrumentation, ensuring data quality and consistency across measurement campaigns.
  \- Co-presented poster on ML-based soil moisture retrieval at national soil moisture workshop, demonstrating research outcomes to the scientific community.
  \- Developed interactive data visualization dashboards using Vue.js to improve accessibility and real-time analysis of field measurements.
  \- Pursued formal certifications in remote sensing, transitioning expertise from electromagnetics to geospatial science applications.

- **Independent Research & Development Consultant**   2020 − 2022
  \- Transitioned back to India during COVID-19 pandemic while pursuing postdoctoral opportunities and preparing academic grant proposals for faculty positions.
  \- Developed Python-based analytical tools for financial market analysis and algorithmic trading strategies using WebSocket APIs.
  \- Created machine learning pipelines for healthcare datasets and designed user interfaces using frameworks like Gradio.
  \- Applied time-series modeling and signal extraction techniques across diverse domains, expanding expertise in data-driven decision-making.
  \- Maintained active problem-solving engagement through collaborative projects during the global pandemic transition period.

- **FNRS Research Fellow**, eRoot Project, UCLouvain, Belgium   2016 − 2020
  \- Developed pioneering computational models for soil-root electrical interactions with unprecedented anatomical fidelity under FNRS grant T.1088.15, among the first studies globally to explicitly incorporate root anatomy in FEM-based geoelectrical models.
  \- Generated detailed finite element meshes representing realistic maize root architectures containing up to 500,000 tetrahedral elements for coupled electrical and hydrological simulations.
  \- Extended modeling framework to field-scale scenarios, investigating electrical anisotropy as a non-invasive proxy for root phenotyping and exploring root tissue polarization effects on geoelectric signatures.
  \- Developed Python-based automation pipelines to process thousands of root system geometries, enabling statistical validation of structure-signal relationships at scale.
  \- Utilized high-performance computing resources at Forschungszentrum Jülich supercomputing facility for large-scale simulations and model validation.
  \- Published multiple peer-reviewed journal articles advancing the state of knowledge in root system biophysics and soil geoelectrics.

- **Research Assistant**   2010 − 2016

  University of Paderborn, Germany   2015 − 2016
  \- Developed FORTRAN code to simulate excitonic resonances in two-level systems for optical pulse delay applications, matching experimental delay times observed at Dartmouth for optical communication and processing applications.
  \- Implemented Maxwell-Bloch equations using advanced numerical methods including high-

order Runge-Kutta schemes, finite difference methods, and careful time-step optimization for solution stability.
- Conducted numerical simulations to model photon-matter interactions in engineered two-level systems for optical signal processing under DFG funding.

Alabama A&M University, USA   2013 – 2014
- Conducted experimental and theoretical research on photodegradation mechanisms using various dye molecules including Rhodamine 6G under controlled laser illumination.
- Performed photo-patterning and photo-deposition of biosensing molecules on polymer thin films, utilizing clean room facilities and precision optical setups.
- Operated and maintained high-value laser systems ($5,000-$100,000) including UV lasers, lock-in amplifiers, oscilloscopes, and optical test benches with nanometer-scale precision.
- Characterized biomolecule deposition patterns using Atomic Force Microscopy (AFM), including delicate probe handling and instrument calibration in clean room environments.
- Served as Teaching Assistant for Physics 101, supporting undergraduate laboratory instruction and coursework.

University of Alabama in Huntsville, USA   2010 – 2013
- Extended existing 2D electrostatic Particle-in-Cell (PIC) simulation code into a fully functional 3D electromagnetic framework under NSF grant ATM0647157.
- Developed custom modules to simulate magnetic field configurations, implementing Helmholtz coil field generation from scratch for plasma thruster digital modeling.
- Created high-fidelity digital twin of plasma thruster capturing key physical phenomena including wave-particle interactions and plasma instabilities observed in laboratory experiments.
- Implemented parallel computing strategies using MPI and optimized code components with OpenMP for scaling on Alabama's supercomputing infrastructure.
- Contributed to peer-reviewed publications in *Physics of Plasmas* through low-level code development, Linux-based automation, and high-performance computing implementations.

Teaching & Communication

- **Content Creator - Phenorob Digital Agricultural Avatar, Forschungszentrum Jülich**   2023 – 2024
  - Produced tutorial videos on how to install, configure, and use agricultural models (e.g., AgroModels).
  - Created Docker walkthroughs, terminal-based model execution guides, and troubleshooting guides.
  - Conducted interviews with model developers, explaining the inner workings of various agro-models.
  - Developed video documentation to support researchers and practitioners in digital agriculture.

- **Content Creator**   2024 – Present
  - Experienced in academic research, grant writing, and publishing. Active in scientific communication and education through multiple channels including technical writing and educational content creation.

- **Workshop Instructor - UCLouvain, Belgium**   2018
  - Conducted a MATLAB workshop on inverse parameter fitting for soil hydraulic modeling.
  - Taught non-linear least squares fitting techniques for estimating van Genuchten parameters.
  - Demonstrated soil moisture retention curve fitting using MATLAB's optimization toolbox.

- **Graduate Teaching Assistant - Alabama A&M University, USA**   2013 – 2014

- Taught Physics 101, covering mechanics, electrostatics, and fundamental physics principles.
- Conducted laboratory sessions and assisted undergraduate students with hands-on experiments.
- Graded assignments, prepared course materials, and provided academic support to students.

Fellowships & Grants

- FNRS Research Fellowship, UCLouvain   2016 – 2020
- DFG Research Fellowship, University of Paderborn   2015 – 2016
- NSF Fellowship, University of Alabama in Huntsville   2011 – 2012

Publications

Journal Articles

1. Rao, S., et al. (under review). When Does Random Forest Soil-Specific Calibration Improve SAR-Based Soil Moisture Estimates? A Comparative Study. *Remote Sensing Letters*, submitted.

2. Rao, S., et al. (under review). Process-Based Modeling and Model Coupling for Agricultural Digital Twins: A Comprehensive Review. *In Silico Plants*, submitted.

3. Rao, S., et al. (2020). Imaging plant responses to water deficit using electrical resistivity tomography. *Plant and Soil*, 29 citations.

4. Rao, S., et al. (2020). Sensing the electrical properties of roots: A review. *Vadose Zone Journal*, 19(1), 71 citations.

5. Rao, S., et al. (2019). Impact of maize roots on soil–root electrical conductivity: A simulation study. *Vadose Zone Journal*, 18(1), 35 citations.

6. Singh, N., Rao, S., et al. (2013). Waves generated in the plasma plume of helicon magnetic nozzle. *Physics of Plasmas*, 20(3), 27 citations.

7. Rao, S., Singh, N. (2012). Numerical simulation of current-free double layers created in a helicon plasma device. *Physics of Plasmas*, 19(9), 39 citations.

8. Singh, N., Rao, S. (2012). Plasma turbulence driven by transversely large-scale standing shear Alfvén waves. *Physics of Plasmas*, 19(12), 3 citations.

Book Chapters

1. **Rao, S.**, Ranganath, P. (2025). Climate-Resilient Agriculture: Leveraging Language Models for Mitigation and Adaptation. In *Mitigation and Adaptation Strategies Against Climate Change in Natural Environments*.

2. **Rao, S.**, Ranganath, P. (2025). Unmanned Aerial Vehicles (UAVs) as Sensor-Driven Data Feeders for Agricultural Digital Twins *Book Chapter submitted to Taylor & Francis for publication.*

3. Ranganath, P., **Rao, S.** (2025). Quantum Computing in IoT-based Military Applications In *Quantum Computing, Sensing and Communications for IoT*. Springer Studies in Computational Intelligence Series. (Accepted).

Conference Presentations

1. Rao, S., et al. (2019). Investigation of Electrical anisotropy as a root phenotyping parameter: Numerical study with root water uptake. *Geophysical Research Abstracts*, 21.

2. Rao, S., et al. (2019). Relationship between electrical anisotropy of soil-root continuum and geometrical architecture of root system. *National Symposium for Applied Biological Sciences*.

3. Rao, S., et al. (2017). A forward model for electrical conduction in soil-root continuum: a virtual rhizotron study. *4th International Workshop on Geoelectrical Monitoring*.

4. Rao, S., et al. (2017). Characterizing root system characteristics with Electrical resistivity Tomography: a virtual rhizotron simulation. *EGU General Assembly Conference Abstracts*.

Peer Review & Professional Service

- Reviewer for *Nordic Machine Intelligence*
- Reviewer for *Plants in Silico*
- Reviewer for *PeerJ Computer Science*
- Reviewer for *Plant and Soil*
- Reviewer for *Vadose Zone Journal*
- Grant proposal reviewer

Technical Experience

Programming: Python, C++, FORTRAN, MATLAB, JavaScript (Vue.js), HTML/CSS
ML Frameworks: TensorFlow, PyTorch, Scikit-learn, Keras
Software Engineering: Docker, Git, CI/CD, WebSockets, API Development, Hugo
Computing: MPI, OpenMP, HPC clusters, Linux systems, Parallel computing
Modeling: Numerical Methods, PIC plasma simulations, time-series, Digital twins, Model coupling
Data Science: Time series analysis, Random Forest, Cross-correlation, Anomaly detection
Instrumentation: AFM, Geoelectric Methods, Satellite remote sensing, Lock-in amplifiers, Optical test benches

Professional Development

- Land in Focus - Basics of Remote Sensing, EO College   November 2022
- Advanced HPC training workshops and computational modeling courses

Volunteer Experience

Blog Committee Member — Young Hydrologic Society (YHS)   April 2025 – Present
- Selected to contribute to the YHS Blog Committee, creating educational content for early career hydrologists.
- Develop blog posts on topics related to computational hydrology, digital twins, and environmental modeling.
- Support the YHS mission of promoting participation of early career researchers in the hydrologic science community.