SocRob@Home 2025 Team Description Paper

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Abstract. The SocRob@Home team has an extensive history in scientific competitions, recently participating in RoboCup 2021, 2023, and 2024. Our contributions span a range of topics, particularly focused on human assistance in home environments. For RoboCup 2018 and 2021, we developed a person-of-interest tracking and following system, and an open-source Petri net-based decision-making toolbox for planning under uncertainty, the latter supported by RoboCup/Mathworks Research Projects and showcased in the 2021 open challenge.

In preparation for RoboCup 2023, we advanced a Petri net-based approach for optimizing action plans based on individual speech commands, accounting for action duration uncertainties, and applied it to the General Purpose Service Robot (GPSR and EGPSR) tasks.

Currently, the team is addressing research challenges across sensor calibration, perception, manipulation, task planning, and human-robot interaction. This includes developing an automated method for the extrinsic calibration of multiple 3D sensors relative to each other and a mobile base, improving full-body navigation techniques for wheeled mobile robots to use manipulators while moving on a 3D world, and integrating grasp pose estimation. We are also exploring a manipulation closed-loop feedback system using reinforcement learning, particularly valuable in dynamic environments.

In task planning, we are building an end-to-end pipeline that leverages a Large Language Model to translate instruction transcripts directly into action plans, with environmental context incorporated to improve efficiency and relevance. This system, successfully deployed at RoboCup 2024 in Eindhoven, was initially tested in a simulator based on Generalized Stochastic Petri Nets.

In the area of localization and navigation, team members are exploring active SLAM using frontier algorithms and investigating 3D localization and navigation using 3D Lidars. Additionally, efforts are underway to enhance modularity and transferability across functionalities.

1 Introduction and Scientific Background

The SocRob@Home team has represented ISR/IST at RoboCup, the world's foremost scientific event in artificial intelligence and robotics, since 1998. Originally launched as an extension of the SocRob (Soccer Robots or Society of

Robots) research initiative, SocRob@Home has participated in various RoboCup leagues, including Simulation, 4-Legged, Middle Size, and Robot Rescue, across several RoboCup World Championships and regional RoboCup events like the Portuguese, German, and Dutch Opens.

Over the past 24 years, the project has engaged more than 100 students, from early master's students to Ph.D. researchers. With this history, SocRob@Home has reached a significant level of maturity, enabling the development of complex behaviors that integrate foundational robot skills such as navigation, perception, and manipulation. This foundation supports the team's current focus on elaborate household tasks, such as those featured in the RoboCup @Home League.

Our team had early opportunities to expand in this domain by participating in the RoCKIn Camp in 2014 and 2015, which provided hands-on experience and theoretical knowledge. The team also demonstrated its capabilities by winning the ”Best in Class for Manipulation” award in 2014[1] and the ”RoCKIn@Home Benchmarking” award in 2015. This success continued in the German Open @Home League in Magdeburg in 2015 and 2017, where SocRob received the ”Most Appealing Robot” award for exceeding expectations as a newcomer to this advanced competition.

At RoboCup 2018 in Montreal, SocRob@Home advanced to the Bronze Cup finals[2], with the “Help Me Carry” task highlighting the team's development of a reliable person-following algorithm[3]. In 2019, the team participated in the ERL SciRoc Smart Cities competition in Milton Keynes, focusing on the “Deliver Coffee Shop Orders” task.

In 2021, SocRob participated in RoboCup's first virtual competition, developing and showcasing an open-source Petri net toolbox [1] as part of the RoboCup/Mathworks Research Projects. This project aimed to coordinate multi-robot systems under uncertain action[4], demonstrated by a group of floor-vacuuming robots tasked with optimizing cleaning time.

Returning in 2023 for RoboCup in Bordeaux, SocRob@Home reached the finals and placed second, achieving high scores in both the Generic Purpose Service Robot (GPSR) and Extended GPSR tasks[5]. An unprecedented feat that led to the team receiving the GPSR Overbot award (Best in GPSR and EGPSR).

Most recently, SocRob@Home secured third place at RoboCup 2024 in Eindhoven [6], alongside notable teams like Tidyboy and NimbRo@Home, thereby reaffirming the team's status among the top RoboCup performers.

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[1] `youtu.be/0STWX9SHo1I`

[2] `youtu.be/P4QA02b6ihA`

[3] `youtu.be/CE4aKsvtkzE`

[4] `youtu.be/Pjq8B8gG35o`

[5] `https://youtube.com/playlist?list=PL8fxtCUfhUR0uuf8OyvP0e0697qhDL63N&si=ANBRFP6jlIuQUmVo`

[6] `https://youtube.com/playlist?list=PL8fxtCUfhUR3CmQjfDQYqrPcwrP-cY5b6&si=-qDiMK-IT8vsfG3T`

Over the years, the team has maintained video recordings of performances from these competitions. All of these recordings, including footage from recent RoboCup events, are available on SocRob's YouTube channel[7].

At SocRob headquarters, we benefit from an official ERL testbed, ISRoboNet@Home[8], which allows the team to test the robot's abilities in a real-world apartment environment. This setup enables benchmarking using an OptiTrack® system for state-of-the-art localization.

SocRob@Home is dedicated to tackling scientific challenges related to deploying robots in domestic settings to assist people. The team's broader objectives include inspiring young researchers with teamwork-driven solutions to engineering problems across a spectrum of disciplines, from hardware and wireless communications to software engineering, navigation, and control. Our work integrates elements of modern information and communication technology (e.g., mobile wireless networks for robot systems) to build a solid foundation for developing versatile, forward-thinking engineers and researchers.

The remainder of this paper is structured as follows: Section 2 outlines our research objectives and summarizes past achievements through SocRob's participation in @Home-type competitions, and Section 3 details ongoing research efforts by current team members. Finally, the appendix provides an in-depth overview of the robotic platform planned for RoboCup@Home 2025.

2 Research Focus

Domestic robotics is an expanding field with applications that range from basic cleaning robots to sophisticated companion robots designed to care for the elderly and individuals with special needs at home.

To achieve this level of assistance, robotic systems must address challenges across several key areas, including mapping, localization, navigation, perception, manipulation, decision-making, and human-robot interaction.

Our research objectives specifically target advancements in each of these critical areas.

- ***Sensor Calibration*:** Our research in this area focuses on developing an automated approach for extrinsic calibration of multiple 3D sensors relative to each other and a mobile base. This method employs custom 3D-printed geometric targets and leverages the Iterative Closest Point (ICP) algorithm. The primary aim of this project is to establish a reliable, automated calibration system that accurately determines the positions and orientations of 3D sensors on a mobile robotic platform.
- ***Mapping, Localization and Navigation*:** To maintain a semantic map of the environment, we employ a hierarchical system combining a coordination and knowledge representation layer with an execution layer. In a domestic context, we represent each room as a subset of the global world model and

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[7] `https://www.youtube.com/@socrob_home`

[8] `welcome.isr.tecnico.ulisboa.pt/isrobonet/`

structure the decision process within each room as a partially observable Markov decision process (POMDP) with information-based rewards [2].
For localization, we developed an automated method to fine-tune parameters of the robot's localization algorithms [3]. Using the Adaptive Monte Carlo Localization algorithm, this method refines localization accuracy by automatically adjusting parameters based on recorded training datasets.
In navigation, we created a multimodal algorithm to manage diverse scenarios in domestic settings, where navigation must be human-aware, encompassing dynamic collision avoidance and human-guided tasks like escorting and following. Our multimodal navigation approach incorporates the concept of Proxemics to define the robot's optimal distance from humans [4].
More recently, we are advancing full-body navigation for wheeled robots that integrate manipulator actions during movement in a 3D environment. The research focuses on enabling the robot to navigate to a target while positioning its arm as required for specific tasks, such as grasping an object, allowing concurrent base and arm movements to reduce task time, a valuable asset in competition. This approach incorporates obstacle detection and avoidance, critical for managing a dynamic collision zone as the arm adjusts. A Deep Reinforcement Learning solution is being developed to enable the robot to learn efficient navigation strategies, positioning its arm responsively to nearby obstacles, such as moving objects, while reaching target locations in optimal arm configurations.

- ***Perception*:** Our research in this area encompasses various aspects of vision-based robot localization [5], object tracking [6], simultaneous localization and tracking [7], environment modeling [8], laser-based robot localization [9], and vision-based simultaneous localization and mapping [10].
  A significant focus of our work has been on particle filter-based (PF) methods to tackle many perception-related challenges. Specifically, we address two main issues: i) the fusion of noisy sensory information collected by mobile robots that are uncertain about their poses [6], and ii) the scalability of these fusion algorithms with respect to the number of robots in the team [7] and the number of objects being tracked.
  In the domain of Object Detection and Segmentation, we are investigating tools such as Detectron2, an open-source deep learning framework developed by Facebook AI Research for constructing computer vision models.
  Leveraging the image segmentation capabilities of Detectron2, we have developed an Object Position Estimation algorithm. This algorithm utilizes a depth image from an RGB-D camera along with an image mask to estimate object positions, with a focus on calculating the object center.
  We are also exploring algorithms for six degrees of freedom (6DoF) pose estimation. Notably, DOPE [11] and Megapose [12] are examples of algorithms that utilize deep learning techniques to estimate full object poses, heavily tested in BOP Challenges.
- ***Manipulation*:** To enable pick-and-place functionality, we have implemented a visual servoing approach [13] that facilitates the reaching and grasping of objects. This method utilizes an RGB-D camera mounted on the robot's

head to continuously estimate the poses of the end effector and the target object. By calculating the positioning error between these poses, we employ a proportional controller to minimize this error. This approach effectively reduces calibration errors associated with both the camera and the arm joints, as both poses are represented in the camera frame.

Additionally, leveraging RGB-D input, we have developed a second method that incorporates a closed-loop feedback reinforcement learning algorithm. By utilizing camera observations and the robot's positional data, this method executes ideal grasping tasks. The robot can either transition the end effector to a pre-grasping stage, which can then be refined using the aforementioned visual servoing approach, or directly pick up the object if necessary. This closed-loop feedback mechanism also enhances performance in dynamic environments.

Furthermore, we address the grasp pose problem [14], focusing on determining the optimal position and orientation of the end effector for grasping the desired object. This method relies on depth point clouds, making it effective even with previously unknown objects.

- ***Decision Making*:** Within the community addressing the challenges of multi-robot coordination, there is a notable lack of user-friendly software tools that systematically tackle these issues, which stops the development of robust, efficient, and predictable strategies.

  In response to this gap, we have developed two toolboxes [15, 1] that consolidate modeling, planning, and execution algorithms into a single package. These toolboxes implement state-of-the-art, open-source approaches for representing multi-robot systems using generalized stochastic Petri nets with rewards (GSPNRs). Additionally, we introduced an innovative algorithm that streamlines the model design process. This algorithm generates a GSPNR from a topological map and subsequently coordinates the system based on a specified policy.

  Currently, we are working on an end-to-end pipeline where a Large Language Model (LLM) replaces the Natural Language Understanding (NLU) and planning modules. This integration removes the need for an explicit intention extraction module, allowing for the direct translation of user instructions into executable plans for the robot.

  Furthermore, this approach aims to enhance the robot's decision-making capabilities in a manner similar to the GSPN planner by utilizing the robot's acquired knowledge to facilitate recovery in the event of failure. The robot continuously updates a semantic mapping module that stores information gathered from its perception systems, which can then be queried to inform decision-making during task execution. By merging the robot's acquired knowledge with the common-sense knowledge embedded in LLMs, we aim to enable more efficient planning. An additional key objective is to develop a model resilient to Automatic Speech Recognition (ASR) errors, enabling the robot to leverage its understanding of the environment to correct potential transcription mistakes.

- ***Human-Robot Interaction*:** The team is currently working on applying deep representation and reinforcement learning methods to enable service robots mobile robots with the ability to infer, track and reason about the belief, desire and intentions of others (human and robots) in joint tasks.
  In this context, we previously developed a method for following a person of interest [16]. This approach utilizes a general-purpose object detector, a multi-tracker for individuals, and a navigation strategy that incorporates a navigation stack employing the Fast Marching Method as a global planner and the Dynamic Window Approach as a local planner.
  Additionally, we have tackled the problem of people re-identification [17], which involves enabling a domestic robot to recognize, identify, and re-identify individuals. This process entails determining whether a person is present among a set of candidates and recalling their identity over time. To achieve this, we combined existing techniques, such as a people detection algorithm, a people localization algorithm, and a re-identification feature extractor tool [18], all within a Kalman filter framework that facilitates simple data association and track management.

3 Team Members

- **Afonso Certo** is a MSc student developing a end-to-end planning pipeline based on LLMs that converts the transcript of the audio command to a complete action plan to be executed by the robot.
- **André Silva** is a Research Engineer working on visual servoing.
- **António Morais** is a BSc student working on 3D Path Planning and Guidance.
- **Catarina Caramalho** is a BSc student studying 3D Localization approaches.
- **Gabriel Nunes** is a lab technician, working on the design, construction and assembly of the electric, electronic and mechanical hardware.
- **Kevin Alcedo** is a PhD student tackling HRI challenges using DL representation and RL methods to enable service robots with the ability to infer, track, and reason about the belief, and intentions of others in joint tasks.
- **Matilde Vital** is an MSc student working on object detection and segmentation algorithms.
- **Miguel Nabais** is a MSc student working on grasping. Currently he is developing a RL algorithm that makes use of training through trial and error with the objective to create a general grasping solution.
- **Patrícia Torres** is a BSc student looking into 3D Mapping techniques.
- **Pedro Lima** is a faculty member which has been involved in robot competitions since the first editions of the RoboCup and European Robotics League events. He is the project coordinator.
- **Robin Steiger** is an MSc student working on multi-objective active SLAM using the frontier algorithm and full map posteriors.

- **Rodrigo Coimbra** is an MSc student developing a RL full-body navigation method to control a service robot on a 3D world.
- **Rodrigo Serra** is a research engineer addressing the person re-identification problem using deep learning methods, and 6dof full pose estimation of objects. He is the current team leader.
- **Rui Bettencourt** is a PhD student, working on full-body navigation techniques for wheeled mobile robots to use manipulators while moving on a 3D world, across uneven terrains.
- **Teresa Nogueira** is an MSc student developing an Model Predictive Control (MPC) navigation module.

4 Conclusion

Participating in the RoboCup 2025 will serve as a realistic testing platform for the team members' MSc and PhD thesis. This opportunity is not only an essential step for validating the research conducted throughout the academic year but also a suitable environment to produce new ideas and challenges for future research. Furthermore, it is a unique possibility to contribute to the robotics community.

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SocRob@Home TIAGo Robot Hardware Description

The SocRob@Home TIAGo robot is a customized version of the TIAGo robot developed by PAL Robotics, with the following mechanical specifications:

- **Base:** differential-drive with 1m/s max speed.
- **Torso:** lifting mechanism that moves at 50mm/s and has a stroke of 350mm.
- **Arm:** 7DoF arm with a 2.8kg payload.
- **End-Effector:** Parallel gripper with a linear range of 4cm and 2kg payload.
- **Head:** 2DoF with pan-tilt mechanism.
- **Laptop tray:** with two slots and 5kg payload.
- **Robot dimensions:** height: 110-145cm, base footprint: 54cm.
- **Robot weight:** 72kg.

Fig. 1. TIAGo Robot

Also our robot incorporates the following devices:

- 8W speaker.
- **ReSpeaker microphone array** and head built-in stereo microphones.
- Head mounted **Azure Kinect**, torso mounted **Orbbec Astra S** cameras, and wrist mounted **Realsense d435** cameras.
- Two WiFi Antennas and dual band Wireless 802.11b/g/n/ac interface.
- Inertial measurement unit.
- Three ultrasound sensors with 0.03-1m range.
- Front and back **Hokuyo laser range-finder** with 0.02-5.6m range.
- **Ouster OS1**.
- TP-Link TL-SG108-M2 **2.5G Switch**.
- 720Wh battery.
- Onboard computer with Intel i5 CPU, 8 GB RAM and 250 SSD hard disk.

Robot's Software Description

For our robot we are using the following software:

- **Platform:** Ubuntu 18.04.6 LTS and ROS Melodic.
- **SLAM:** ROS OpenSlam's Gmapping and frontier algorithms.
- **Localization:** ROS implementation of the Adaptive Monte Carlo Localization (AMCL) algorithm.
- **Navigation:** move_base navigation stack.
- **Speech recognition: Whisper**
- **Speech generation:** Acapela Text-to-Speech software.
- **Person and Object recognition and segmentation: Detectron2** and **Yolov8**
- **Manipulation:** ROS MoveIt! framework and **visual servoing implementation.**
- **Task planning:** SMACH ROS library, **Petri net toolbox.** and **LLM Planner**.

External Devices

The SocRob@Home TIAGo robot relies on the following external hardware:

- **Jetson Xavier NX**.
- **Two 15 inch laptop**, with i7 CPU, 16GB RAM, 512GB SSD and NVIDIA RTX 3050.
- 200W **laptop powerbank**.