SocRob@Home 2024 Team Description Paper

Rodrigo Serra, Pedro Lima, Afonso Certo, António Morais, Catarina Caramalho, Clara Pais, Gabriel Nunes, João Pinheiro, Miguel Nabais, Robin Steiger, Rui Bettencourt, Patrícia Torres

Institute for Systems and Robotics (ISR), Instituto Superior Técnico (IST), University of Lisbon, Portugal
`https://irsgroup.isr.tecnico.ulisboa.pt/projects/socrob-home/`

Abstract. The SocRob@Home team has a long record in scientific competitions and recently has participated in ERL Smart Cities 2019, RoboCup 2021, and RoboCup 2023, among other minor events.

The team made several contributions across different topics, of which human assistance in domestic environments is part. In this line of thought, we proposed a multimodal navigation approach that uses the notion of Proxemics to define the distance at which the robot should remain to the humans.

For RoboCup 2018 and 2021, we developed a person-of-interest tracker and follower and an open-sourced Petri net-based decision-making toolbox to plan under uncertainty, respectively. Showcased in the RoboCup 2021 open challenge, the latter was supported by the RoboCup/Mathworks Research Projects. In European Robotics League Smart Cities 2019, we developed a spoken goal-oriented dialogue system capable of dealing with uncertainty in speech recognition and language understanding.

Currently, the team is addressing research problems in different scopes, such as perception, manipulation, task planning, and human-robot interaction. More specifically, we are working to improve person re-identification algorithms based on deep learning-based approaches.

We are also working on visual servoing algorithms and grasp pose estimation integration. On top of this framework, we are exploring a second method, which introduces a closed-loop feedback Reinforcement Learning algorithm. The latter becomes particularly helpful in dynamic environments.

Under the task planning topic, we're developing a Petri net-centered method to identify optimal plans for individual speech commands, considering the uncertainty around action duration. This framework was put into action during RoboCup 2023, demonstrating its application in tasks like the General Purpose Service Robot (GPSR) and the Extended General Purpose Service Robot (EGPSR).

Regarding localization and navigation, we have members exploring active SLAM using the frontier algorithm and studying 3D localization and guidance with 3D Lidars.

Moreover, we have team members working on functionality modularity and transferability.

1 Introduction and Scientific Background

The SocRob@Home team has been representing ISR/IST since 1998 in the world's leading scientific event on Artificial Intelligence and Robotics, RoboCup, as the application side of SocRob (Soccer Robots or Society of Robots) ISR/IST research project.

Until 2013, the team's participation has encompassed Simulation, 4-legged, Middle Size, and Robot Rescue Leagues in several editions of the RoboCup World Championship and various regional RoboCup events, e.g., the Portuguese, German, and Dutch Opens.

The project has involved more than 100 students over these 24 years, from early MSc years to Ph.D. students. At this point, it has reached a maturity level that enables behavior development that integrates low-level robot skills such as navigation, perception, and manipulation into more complex behaviors. Elaborated home tasks, like the ones presented in the @Home League, fall under the scope of such behaviors.

In this line of thought, our team had the chance to participate in the RoCKIn Camp 2014 and 2015 editions. These opportunities gave the team theoretical and hands-on experience in this new domain. SocRob also had the chance to showcase our robot's capabilities, which resulted in the "Best in Class for Manipulation" (2014) [1] and the "RoCKIn@Home Benchmarking" (2015) awards.

In 2015 and 2017, the team joined the RoboCup GermanOpen @Home league hosted in Magdeburg. The competition organizers praised our team as above expectations for a first participation in this challenging league and thus decorated SocRob with the "Most Appealing Robot" award.

In Montereal 2018, we participated in the RoboCup @Home league. We finished among the four best teams and, as a result, reached the Bronze Cup finals[2]. The "Help me Carry" task was one of the highlights of our performance, where we demonstrated a robust person following algorithm[3].

In 2019, we participated in the ERL SciRoc Smart Cities 2019 in Milton Keynes. Our participation mainly focused on the "Deliver Coffee Shop Orders" task.

Two years later, SocRob participated in the first virtual RoboCup. Under the RoboCup/Mathworks Research Projects, the team developed an open-sourced Petri net toolbox[1] to coordinate multi-robot systems under uncertain action durations. The team showcased this toolbox in the RoboCup 2021 Open Challenge[4] as a cooperation task among a group of floor vacuuming robots. The goal was to clean the house in the shortest time possible.

Most recently, the team participated in RoboCup 2023, hosted in Bordeaux, France. After Stages 1 and 2, the team qualified to the final, where SocRob finished second behind Korea's Tidyboy team. Both the competitors and referees

[1] youtu.be/0STWX9SHo1I
[2] youtu.be/P4QA02b6ihA
[3] youtu.be/CE4aKsvtkzE
[4] youtu.be/Pjq8B8gG35o

praised the participation of our team, given our performance in the Generic Purpose Service Robot[5] (GPSR) and the Extended Generic Purpose Service Robot[6] (EGPSR) tasks. It was the first time a team scored in both in RoboCup history and thus, the competition committee awarded the GSPR Overbot award (Best in GPSR and EGPSR) to SocRob.

Over the years, the team has kept video recordings of our performances in these competitions. All the videos are available on SocRob's YouTube channel[7], such as the videos of last year's performance in RoboCup.

In SocRob headquarters, we benefit from an official ERL testbed (ISRoboNet@Home[8]). The testbed allows the team to test the robot's abilities in a real-world apartment scenario while recording benchmark data from a state-of-the-art localization system from OptiTrack®.

Overall, SocRob@Home addresses scientific problems that arise from the effort to deploy robots in the domestic environment to help humans. The broader goals of the team include motivating in young researchers the spirit of working as part of an engineering team to solve engineering problems of diverse types (from hardware to software, including wireless communications, navigation, control, electronics, computer engineering, software engineering), to integrate contributions from modern information and communication technologies (e.g., networked robot systems require a mobile wireless network with robots, off-board computers, external sensors) and to ensure a background that opens doors for future bright multi-faceted engineers or engineering researchers.

The rest of the paper is organized as follows. Section 2 describes our research objectives and past results obtained through SocRob participation in the @Home-type competitions in general. In Section 3, we provide a summary of the current ongoing research of our team members. The appendix provides a detailed description of the robotic platform we intend to use in the RoboCup@Home 2024.

2 Research Focus

Domestic robotics is a rapidly growing field of research with applications ranging from simple robotic machines for house cleaning to companion robots intended to provide care for the elderly or people with special needs at home.

Robotic systems capable of providing such assistance to humans should deal with issues in mapping, localization, navigation, perception, manipulation, decision-making, and human-robot interaction.

We further enumerate our research-specific objectives in these topics through @Home-type participation.

- ***Mapping, Localization and Navigation*:** To maintain a semantic map of the world, we use a hierarchical approach composed of a coordination

[5] `https://youtu.be/pyoB3Dak7ag?si=j9pjtFwyw4CBMuwm&t=1`
[6] `https://youtu.be/Iz-47v1L-zk?si=fVHwbTup90Zs4F1n`
[7] `youtube.com/channel/UCKbYd3H_vSW4ZSD-yn-4-6w`
[8] `welcome.isr.tecnico.ulisboa.pt/isrobonet/`

and knowledge representation layer and an execution layer. In the domestic scenario, we consider each separate room of the home to be a sub-set of the global world representation and model the decision process for each room as a partially observable Markov decision process with information rewards [2]. Under the localization topic, we proposed an automatic method to fine-tune robotics algorithm parameters [3]. Using the Adaptive Monte Carlo Localization algorithm, we improved the localization accuracy of our robot by automatically fine-tuning the localization parameters using several recorded training datasets.

Furthermore, on top of the navigation stack, we developed an algorithm that can handle multiple scenarios in a domestic environment. In this scenario, the robot navigation needs to be human-aware, which spans from dynamic collision avoidance to guiding and following people. These multiple navigation modes were researched and implemented as a multimodal navigation approach [4] that uses the notion of Proxemics to define the distance at which the robot should remain to the humans.

- ***Perception*:** Our research in this domain includes 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].

  Particle filter-based (PF) methods have been the focus of our research to address most perception-related problems. In this line of thought, the challenges we have been addressing include i) fusion of noisy sensory information acquired by mobile robots where the robots themselves are uncertain about their poses [6], and ii) scalability of such fusion algorithms w.r.t. the number of robots in the team [7] as well as the number of objects tracked.

  Regarding the person following algorithm, we developed a method to follow the person of interest. We use a general-purpose object detector, a people multi-tracker, and a navigation strategy that takes advantage of a navigation stack that uses the Fast Marching Method as a global planner and the Dynamic Window Approach as a local planner. This algorithm becomes useful in RoboCup competitions, in tasks such as the Carry My Luggage. This work is open source, and we have made it available to other teams after RoboCup 2018 [11].

  Looking at the Objection Detection and Segmentation domains, we are exploring tools like Detectron2, an open-source deep learning framework for building computer vision models developed by Facebook AI Research. Detectron2 offers a pre-trained model based on the COCO dataset but allows the user to train a custom model based on a predefined dataset. Based on Detectron2 image segmentation capabilities, we develop an Object Position Estimation algorithm. Given a depth image by an RGB-D camera and an image mask, it estimates the position, focusing on the computation of the object center.
- ***Manipulation*:** For the pick and place functionality, we implemented a visual-servoing approach [12] that allows reaching and grasping objects. The method relies on the RGB-D camera in the robot's head to continuously

estimate the end-effector and target poses. Computing the positioning error using both poses, one then uses a proportional controller to minimize this error. This approach mitigates the errors in the calibration of both the camera and the arm joints, as both poses are in the camera frame.
In addition, using the RGB-D input, a second method introduces a closed-loop feedback Reinforcement Learning algorithm. Through camera observations and robot positioning in the world, it performs ideal grasping tasks. The robot can either move the end-effector to a pre-grasping stage, which, from there, can be used by the visual-servoing approach previously described, or even pick the object if needed. This method also helps against dynamic environments due to the closed-loop feedback approach.
We also address the grasp pose problem [13], where we find the most suitable end-effector position and orientation to grasp the desired object. This method relies on the depth point cloud, making it successful even with unknown objects.

– ***Decision Making*:** In prior work, we have addressed the problem of decision-making for teams of autonomous robots. Primarily, we focused on approaches based on the theory of Discrete Event Systems [14] and also through decision-theoretic formalisms for multiagent systems (Partially Observable Markov Decision Processes) [2]. Later, we bridged these two modeling approaches by developing an event-driven decision-theoretic framework[15, 16]. The fundamental insight of this line of research is that decision-making in physical environments is typically an asynchronous, subject to uncertain outcomes and event-driven process over several abstraction layers, in which each layer has limited or uncertain sensorial information.
Within the community tackling this challenge, there exists a shortage of user-friendly software tools designed to systematically tackle challenges in multi-robot coordination, hindering the development of robust, efficient, and predictable strategies.
Bearing this idea in mind, we have proposed two toolboxes [17, 1] that mitigate this issue and encapsulate, in one single package, modeling, planning, and execution algorithms. We implemented open-source, state-of-the-art approaches to represent multi-robot systems as generalized stochastic Petri nets with rewards (GSPNRs). Here, we also introduced a novel algorithm simplifying the model design process. The algorithm starts by generating a GSPNR from a topological map, and secondly, it coordinates the system according to a given policy.
We seek to continue our work on this topic in SocRob@Home [18], noting that the ability to perform decision-making under uncertainty is a fundamental requirement of any potential domestic robot. Given a set of tasks, a robot must manage its priorities by establishing a plan for them and still be able to react reliably to external events.
– ***Human-Robot Interaction*:** The team has focused on service robots in office environments, addressing symbiotic autonomy, i.e., robots execute tasks requested by users while autonomously aware of their limitations, asking humans to help the robot overcome them [19]. More recently, we have been

moving towards speech-based communication to address the requirement of natural human-robot interaction.
We developed a spoken goal-oriented dialogue system [20] capable of dealing with uncertainty in speech recognition and language understanding. We take advantage of statistical frameworks by maintaining uncertainty about what the user has said and exploit the sequential nature of dialogue to disambiguate in the presence of errors.
We also addressed the people re-identification problem [21], where a domestic robot needs to recognize, identify, and re-identify humans, that is, determine if a person is present in a set of candidates and recall a person's identity through time. In this line of thought, we combined existing methods such as a people detector and a people localizer algorithm, a re-identification feature extractor tool [22], and a Kalman filter framework with simple data association and track management. Utilities like Detectron2 and Mediapipe prove valuable in addressing re-identification challenges and more. These tools effectively track facial and bodily features, providing a set of keypoints for subsequent post-processing.

3 Team Members

The team covers a broad range of competencies, from mechatronics integration to high-level decision-making, including perception and human-robot interaction. We briefly describe below the competence of each team member.

- **Afonso Certo** is a MSc student working on GPSR, developing a end-to-end planning pipeline based on large language models that converts the transcript of the audio command to a complete action plan to be executed by the robot.

- **António Morais** is a BSc student working on 3D Path Planning and Guidance.

- **Catarina Caramalho** is a BSc student studying 3D Localization approaches.

- **Clara Pais** is a MSc student working on self-recovery in case of failure during plan execution, used in the GPSR task.

- **Gabriel Nunes** is a lab technician, working on the design, construction and assembly of the electric, electronic and mechanical hardware.

- **João Pinheiro** is a BSc student responsible for a 2D Navigation approach with 3D world information.

- **Miguel Nabais** is a MSc student working on grasping. Currently he is developing a Reinforcement Learning algorithm that makes use of training through trial and error with the objective to create a general grasping solution. He is also addressing the Carry my Luggage task.

– **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. The Restaurant task will work as a case study for his thesis.

– **Rodrigo Serra** is a research engineer addressing the person re-identification problem using deep learning methods. He is also working on the tasks Receptionist and Stickler for the Rules. He is the current team leader.

– **Rui Bettencourt** is a PhD student, working on the cooperation of heterogeneous multi-robot systems as optimization problems.

4 Conclusion

Participating in the RoboCup 2024 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.

References

1. Carlos Azevedo, António Matos, Pedro U. Lima, and Jose Avendaño. Petri net toolbox for multi-robot planning under uncertainty. *Applied Sciences*, 11(24):12087, 2021.
2. J. Messias, M. T. J. Spaan, and P. U. Lima. Efficient offline communication policies for factored multiagent POMDPs. In *NIPS*, pages 1917–1925, 2011.
3. Oscar Lima and Rodrigo Ventura. A case study on automatic parameter optimization of a mobile robot localization algorithm. *ICARSC 2017*, 2017.
4. Rui Bettencourt and Pedro U. Lima. Multimodal navigation for autonomous service robots. In *2021 IEEE International Conference on Autonomous Robot Systems and Competitions (ICARSC)*, pages 25–30. IEEE, 2021.
5. Pedro U. Lima, Pedro Santos, Ricardo Oliveira, Aamir Ahmad, and Joao Santos. Cooperative localization based on visually shared objects. *RoboCup 2010: Robot Soccer World Cup XIV. Lecture Notes In Artificial Intelligence*, pages 350–361, 2011.
6. Aamir Ahmad and Pedro U. Lima. Multi-robot cooperative spherical-object tracking in 3d space based on particle filters. *Robotics and Autonomous Systems*, 61(10):1084 – 1093, 2013.
7. A. Ahmad, G. D. Tipaldi, P. Lima, and W. Burgard. Cooperative robot localization and target tracking based on least square minimization. In *Robotics and Automation, Proceedings of the 2013 IEEE International Conference on*, May 2013.

8. Pedro Vieira and Rodrigo Ventura. Interactive mapping using range sensor data under localization uncertainty. *Journal of Automation, Mobile Robotics & Intelligent Systems*, 6(1):47–53, 2013.
9. João Ferreira, Alberto Vale, and Rodrigo Ventura. Vehicle localization system using offboard range sensor networ. In *Proceedings of IFAC Synposium on Intelligent Autonomous Vehicles (IAV-13)*, 2013.
10. Filipe Jesus and Rodrigo Ventura. Simultaneous localization and mapping for tracked wheel robots combining monocular and stereo vision. *Journal of Automation, Mobile Robotics & Intelligent Systems*, 6(1):21–27, 2013.
11. Enrico Piazza. SocRob project at ISR/IST. `github.com/socrob/bayes_people_tracker`, 2018. [Online; accessed 22-November-2022].
12. Meysam Basiri, João Pereira, Rui Bettencourt, Enrico Piazza, Emanuel Fernandes, Carlos Azevedo, and Pedro U. Lima. Functionalities, benchmarking system and performance evaluation for a domestic service robot: People perception, people following, and pick and placing. *Applied Sciences*, 12(10):4819, 2022.
13. João Gonçalves and Pedro U. Lima. Grasp planning with incomplete knowledge about the object to be grasped. In *2019 IEEE International Conference on Autonomous Robot Systems and Competitions (ICARSC)*, pages 1–6. IEEE, 2019.
14. Hugo Costelha and Pedro U. Lima. Modelling, analysis and execution of robotic tasks using Petri Nets. In *IEEE/RSJ International Conference on Intelligent Robots and Systems*, pages 1449–1454. IEEE, 2007.
15. J. Messias, M. T. J. Spaan, and P. U. Lima. GSMDPs for multi-robot sequential decision-making. In *AAAI*, 2013.
16. J. Messias, M. T. J. Spaan, and P. U. Lima. Multiagent POMDPs with asynchronous execution. In *AAMAS*, pages 1449–1454, 2013.
17. Carlos Azevedo and Pedro U. Lima. A gspn software framework to model and analyze robot tasks. In *2019 IEEE International Conference on Autonomous Robot Systems and Competitions (ICARSC)*, pages 1–6. IEEE, 2019.
18. Pedro U. Lima, Carlos Azevedo, Emilia Brzozowska, João Cartucho, Tiago J Dias, João Gonçalves, Mithun Kinarullathil, Guilherme Lawless, Oscar Lima, Rute Luz, et al. Socrob@ home. *KI-Künstliche Intelligenz*, 33(4):343–356, 2019.
19. Rodrigo Ventura, Brian Coltin, and Manuela Veloso. Web-based remote assistance to overcome robot perceptual limitations. In *AAAI Conference on Artificial Intelligence (AAAI-13), Workshop on Intelligent Robot Systems*, Bellevue, WA, 2013. AAAI.
20. João Barroca. A Spoken Goal-Oriented Dialogue System for Service Robots. `fenix.tecnico.ulisboa.pt/cursos/meaer/dissertacao/283828618790451`, 2019. [Online; accessed 22-November-2022].
21. Vicente Pinto. People Recognition and Identification in Service Robots. `fenix.tecnico.ulisboa.pt/cursos/meec/dissertacao/1128253548922906`, 2021. [Online; accessed 22-November-2022].
22. Alexander Hermans, Lucas Beyer, and Bastian Leibe. In defense of the triplet loss for person re-identification. *arXiv preprint arXiv:1703.07737*, 2017.
23. J. Messias. The mdm package: Software description and deployment guidelines. Technical report, Institute for Systems and Robotics, 2013.
24. João Cartucho, Rodrigo Ventura, and Manuela Veloso. Robust object recognition through symbiotic deep learning in mobile robots. In *2018 IEEE/RSJ international conference on intelligent robots and systems (IROS)*, pages 2336–2341. IEEE, 2018.

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** and torso mounted **Orbbec Astra S** 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.
- 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.
- **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**
- **Manipulation:** ROS MoveIt! framework and **visual servoing implementation.**
- **Task planning:** SMACH ROS library and **Petri net toolbox.**

Robot software and hardware specification sheet

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**.