SocRob@Home: Team Description Paper for RoboCup@Home 2016

Rodrigo Ventura, André Mateus, João Garcia, Meysam Basiri, Pedro Miraldo,
Pedro Santos, Pedro U. Lima

Institute for Systems and Robotics
Instituto Superior Técnico
University of Lisbon, PORTUGAL
`http://socrob_at_home.isr.tecnico.ulisboa.pt`

1 Introduction and Scientific Background

The SocRob 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. The project has involved more than 50 students over these 18 years, from early MSc to PhD students, and has reached a maturity level that enables behavior development supported by a realistic simulator, with a GUI, where the actual code running in the robots is tested and then ported to the real hardware. 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. Since 2013 the team decided to focus exclusively on the vibrant and extremely interdisciplinary league of RoboCup@Home.

The participation in the camps and competitions promoted by the EU RoCKIn project[1] provided a crucial boost to leverage our competence for @Home competitions. We were in the RoCKIn Camp 2014, organized in Rome, Italy, where we received the award for "Best in Class for Manipulation"[2]. We then participated in the 'FreeBots' league in the Portuguese Robotics Open 2014, where we successfully demonstrated our robot assisting its owner in a real domestic environment[3]. In March 2015 we traveled to Peccioli, Italy, for the RoCKIn Field Exercise 2015, where our robot was demonstrated in the intelligent home of ECHORD++ RIF at U. Pisa's Service Robotics and Ambient Assisted Living Lab, winning the RoCKIn@Home Benchmarking Award. More recently, we competed in the @Home league of the RoboCup GermanOpen 2015 event in Magdeburg, where we received the "Most Appealing Robot Award". Finally, we participated in the RoCKIn 2015 final competition event[4], where we received

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[1] http://rockinrobotchallenge.eu

[2] http://youtu.be/0STWX9SHo1I

[3] https://youtu.be/4mF0_5MCgpw

[4] https://youtu.be/ooO0LTiJsUc

several awards at the RoCKIn@Home competition: first place among 9 participating teams in two of the three Task Benchmarks, and the overall @Home winners ex-aequo with the team Homer from University of Koblenz, Germany.

Participation of SocRob@Home in robot competitions will act as a case study for a nationally funded research project on domestic robots (just started) and for part of the research developed under the EU-FP7 project MOnarCH[5], which our group is currently coordinating and where most of our team members are also involved directly. The mobile robot used in SocRob was developed under MOnarCH and, later, endowed with a robotic arm.

The broader goals of SocRob include teaching young researchers: to work 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.

2 Research Objectives and Goals

Domestic robotics is a rapidly growing field of research, with applications ranging from simple robots for house cleaning to much smarter companion robots intended to provide care for the elderly at home. Robotic systems, capable of providing such assistance to humans, must address not only traditional robotics research topics (such as sensor-fusion, task and motion planning, navigation, and manipulation), but should also posses a highly natural human-robot interaction skills. Our goal is to develop domestic robot systems, being part of a network of heterogeneous devices, that perform different duties while interacting seamlessly with humans. In the following subsections we detail our research-specific objectives motivated by participation in domestic robot competitions.

2.1 Perception and Sensor Fusion

Our research in this domain includes: vision-based robot localization [8]; object tracking [2]; simultaneous localization and tracking (SLOT) [1]; laser-based robot localization [5]; and vision-based simultaneous localization and mapping (SLAM) [7]. Particle filter-based (PF) methods have been the focus of our research, to address most perception-related problems. Using PF's, the key issues that we have been engaged in solving include: fusion of noisy sensory information acquired by mobile robots, where the robots themselves are uncertain about their own poses [8] [2]; and scalability of such fusion algorithms (w.r.t. the number of robots in the team [1]).

For a domestic service robot working in a @Home-type environment, localization, mapping and object/person tracking constitute the basic requirements.

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[5] http://monarch-fp7.eu

In addition to this, static sensors along with mobile robots in a Networked Robot System (NRS) introduce further challenging issues for sensor-fusion algorithms. Considering these, we intend to actively drive-forward our perception-related research in SocRob@Home.

2.2 Decision-Making

In prior work, we have addressed the problem of decision making for teams of autonomous robots through approaches based on the theory of Discrete Event Systems [14,13,4] and decision-theoretic formalisms for multiagent systems (Partially Observable Markov Decision Processes) [9]. Recently, we have bridged these two modeling approaches, through the development and application of event-driven decision-theoretic frameworks [10,11]. The fundamental insight of this line of research is that decision making in physical environments is typically an asynchronous, event-driven process over several levels of abstraction, based on limited or uncertain sensorial information over each level, and subject to uncertain outcomes. We have explored this approach in the CMU-Portugal MultiAgent Surveillance Systems (MAIS+S) project[6], where we have successfully implemented an NRS for autonomous surveillance, comprising a team of mobile robots and a set of stationary cameras. We are currently applying some of these concepts to symbiotic interaction with autistic children and staff in a hospital, under a new CMU-Portugal project INSIDE[7].

We seek to continue our work in this topic in SocRob@Home, noting that the ability to perform decision-making under uncertainty is a fundamental requirement of any potential domestic robot, for example: given multiple tasks, such a robot must be able to manage their priorities; establish a plan for each of them; and still be able to react reliably to external events. The (possibly symbiotic) interaction with humans can also be modeled as a partially observable decision making problem. We are investigating approaches of this kind where humans interact with the robot through gestures and speech.

2.3 Human-Robot Interaction

We have focused on serviced robots in office environments, addressing in particular symbiotic autonomy: robots execute tasks requested by the users while autonomously being aware of their own limitations and asking the help of humans for overcoming them [16]. More recently, we have been moving towards speech-based communication, in order to address the @Home requirement of natural human-robot interaction. However, all communicative acts accessible from voice are also accessible through the robot touchscreen.

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[6] http://gaips.inesc-id.pt/mais-s/

[7] http://gaips.inesc-id.pt/inside

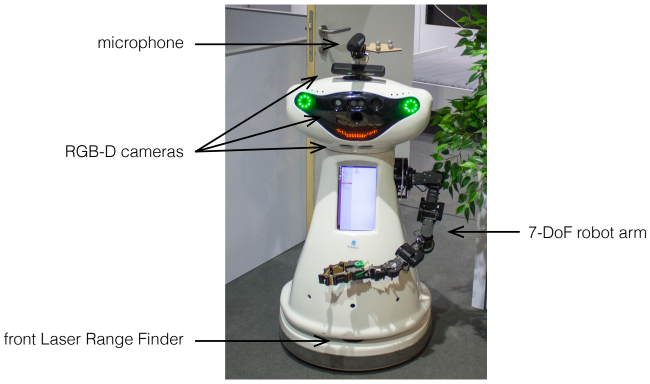

Fig. 1. Robot platform of SocRob@Home.

3 Robot Description (Hardware and Software)

Our robot builds upon a 4-wheeled omni-directional robot platform, shown in Fig. 1. This robot has been specifically developed for an ongoing European FP7 project: MOnarCH[8]. In addition to various other sensors and actuators described in [12], it is equipped with two laser range finders, a Kinect RBG-D camera and a display with touch screen. On top of this platform, we installed additional devices, namely: a 7 DoF arm for manipulation (Robai Cyton Gamma 1500), a directional microphone for speech interaction (Røde VideoMic Pro), and an additional RGB-D camera (Asus Xtion PRO Live) for object detection, recognition, and localization. The software architecture is based on ROS for middleware, while using off-the-shelf components whenever possible. This allows the team to focus on our research interests.

3.1 Navigation

We take the classical approach of dividing navigation into self-localization and guidance, assuming knowledge of a map of the environment. We also assume that unmapped static or moving obstacles may appear in the environment, while the robot is expected to deal with them in an appropriate way. The guidance problem is approached as a two step process. Initially the robot plans its path from the current position towards the goal position, and then the robot executes the plan while avoiding unmapped obstacles. For navigation, we use a standard occupancy grid map, obtained from off-the-shelf SLAM software[9]. This map is used for localization, using off-the-shelf software[10] and for motion planning.

Our path planning is based on the Fast Marching Method (FMM) [15] approach. Given a map constraining the workspace of the robot and a feasible goal

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[8] Project reference: FP7-ICT-2011-9-601033

[9] GMapping (`http://wiki.ros.org/gmapping`, retrieved 16-Oct-2013).

[10] AMCL, (`http://wiki.ros.org/amcl`, retrieved 16-Oct-2013).

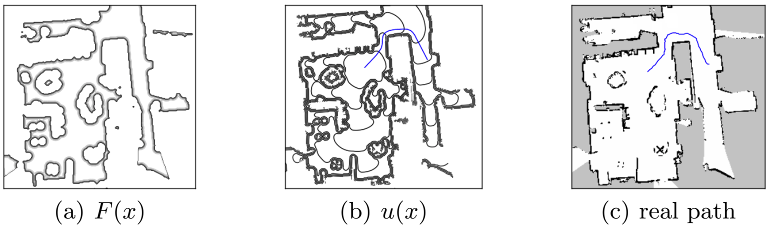
(a) $F(x)$ (b) $u(x)$ (c) real path

Fig. 2. Motion planning using FMM: (a) the cost function $F(x)$ (darker means a higher cost), (b) the solution field $u(x)$ (level curves) together with the gradient descent $\dot{x}(t) = -\nabla u(x)$ solution (from the right to the left), and (c) the real path traveled by the robot.

point, a potential field $u(x)$, for $x \in R^2$, is constructed such that the path towards the goal is obtained by solving the ordinary differential equation $\dot{x}(t) = -\nabla u(x)$. Fig. 2 shows the results of this approach in an experiment.

The guidance and obstacle avoidance algorithm is based on a Dynamic Window Approach (DWA) [6,3]. Given the robot's current velocity, pose, and available sensor data, the next motion velocity command is computed. This is done by formulating a constrained optimization problem, over a discrete set of candidate velocity commands. The outline of the algorithm is the following:

1. Generate a set of candidate linear velocity commands;
2. Discard the velocity values beyond a specified maximum absolute value;
3. Discard the velocity values which could lead to a collision
4. Compute a fitness value for each candidate, by weighting three contributions: progress towards the goal; clearance from obstacles; and absolute speed;
5. Select candidate, maximizing the evaluation value;
6. Compute angular velocity based on the direction of the selected linear velocity, such that the robot front tends to be aligned with the motion direction.

This algorithm follows closely the DWA as initially proposed in [6], except for novel methods for both computing the clearance, taking into consideration the robot shape, and the progress, based on the potential field obtained from FMM. Further details can be found in [12].

3.2 Manipulation

We are using Robai Cyton Gamma 1500, a 7-DoF manipulator, mounted on the base platform. The arm weight is about 2Kg, with a payload of 1500g. The drivers for ROS were re-written by the team, building on top of the low-level drivers provided by the manufacturer. Motion planning is performed by the MoveIt! library, also available for ROS. This library supports collision avoidance of the arm with obstacles (namely the robot body) during motion execution.

3.3 Interaction with users

Our platform supports two interaction modalities: touch interface over a Graphical User Interface (GUI), and speech synthesis and recognition. Text-To-Speech (TTS) employs the eSpeak[11] package while Automatic Speech Recogniton (ASR) is based on VoCon Hybrid[12], a state-of-the-art commercial solution. ASR is grammar based with the grammars created based on prior lexical knowledge of the scenarios that the robot needs to understand. To improve recognition rate, a confidence-based threshold is defined so that utterances may be discarded. Speech understanding is based on the definition of a grammar over a corpus, which spawns the possible sentences the ASR recognizes.

Speech interface is currently task-oriented, i.e., the dialogue with the user is tailored towards the execution of a specific task. Our multi-modal dialogue system is based on a FSM, that coordinates the emission of canned sentences to both the TTS and the GUI, where the transitions depend on the user response (either through the ASR or the GUI). All user responses are explicitly confirmed by the robot. The outcome of each dialogue session is fed in to the main FSM, to guide the robot behavior accordingly.

3.4 Task representation and execution

In terms of task representation and execution our approach is based on SMACH[13] which allows to represent and execute hierarchical and concurrent state machines. Our approach consists in a predefined or on-line composition of the tasks using high level state machines that address the decision-making problem and the tasks goals. High level state machines are implemented through low level state machines, with well-known outputs, based on states that address atomic functionalities like actions or conditions verifications.

3.5 Object recognition

The object recognition module is based on the 3D recognition framework of the Point Cloud Library[14]. To acquire the point clouds, we use a RGB-D camera on top of the robot. It comprises two modules: a training module; and a recognition module. The training module imports models for an object class in binary PLY format. These models are then rotated and converted to point clouds, from different views, and several keypoints are extracted. The recognition process comprises three main steps: loading of the information required by the module; making the scene segmentation; and identifying clusters of objects. The loading stage will load all the models available to the recognizer as well as specific information needed for the segmentation and coordinate conversions. Then the

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[11] http://espeak.sourceforge.net/

[12] http://www.nuance.com/for-business/speech-recognition-solutions/vocon-hybrid/index.htm

[13] http://wiki.ros.org/smach

[14] http://pointclouds.org

module will have to use either the tabletop segmentation, for when objects are on a flat surface, or the 3D background subtraction, used (for example) when objects are on a a bookshelf. In either case the module will select the area of interest in the scene and apply a clustering algorithm to the point cloud to extract the position of the object. To classify clusters, a recognizer is trained with the previously processed models that presents the most likely correspondences.

3.6 People detection

For person recognition, we developed a ROS action server which executes two different goals. The first consists in learning someone's face, by taking multiple pictures of the face with different orientations and facial expressions. The second is the face recognition using a pre-defined number of frames that is based on the OpenCV FaceRecognizer. Apart from recognizing people, the robot can also track people using the onboard MS Kinect. The algorithm consists of two steps: person identification; and tracking. The former starts by segmenting the depth image with Watershed threshold. The segmented image is then filtered to identify blobs with similar dimension to humans. The validation of the person candidates is verified with the RGB image, by training a SVM, using the Histogram Oriented Gradients, both with positive and negative samples. In order to prevent a high percentage of false positives, this method is combined with the OpenCV Haar Cascade for detecting people's upper bodies. The 3D location and speed of each blob is computed with a Kalman filter. After compensating the element's motion with the robot's egomotion (provided by the IMU), an iterative process is executed to find the best match.

4 Conclusions

SocRob@Home is currently part of a nationally funded research project on domestic robots under which the participation in RoboCup competitions represents an important case study. We plan to use the datasets of our participation in RoboCup 2016 to benchmark our results on the major scientific challenges of the project. Nevertheless, we will recur to off-the-shelf software components, when available, to speed up the development process of our robot system, as well as to make it more dependable and competitive. These components are integrated with novel outputs of our own research using ROS.

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Team Name: SocRob@Home

Team Coordinator: Rodrigo Ventura

Team Members: Rodrigo Ventura (Professor and Team Coordinator), Pedro U. Lima (Professor and SocRob Project Cordinator), Meysam Basiri (Post-Doctoral Researcher), Pedro Miraldo (Post-Doctoral Researcher), Tiago Veiga (Post-Doctoral Researcher), André Mateus (PhD Student), José Iglésias (MSc Student), João Garcia (MSc Student), Luis Luz (MSc Student), Nuno Mendes (MSc Student), Ricardo Simas (MSc Student), Diogo Maximino (MSc Student) **Web:** http://socrob_at_home.isr.tecnico.ulisboa.pt **E-mail:** rodrigo.ventura@isr.tecnico.ulisboa.pt