SocRob@Home: Team Description Paper for the Competition Event RoCKIn@Home 2014

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I. TEAM DETAILS

- **Team Name:** SocRob@Home
- **Team Coordinator:** Pedro Lima
- **Team Leader:** Rodrigo Ventura
- **Team Members:** João Messias, Aamir Ahmad, João Mendes, Filipe Jesus, Diogo Pires, Pedro Resende, André Farinha, André Mateus, Isabel Ferreira, and João Sequeira
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II. 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 40 students over these 16 years, from early MSc years 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.

With the current state-of-the-art capabilities, SocRob now aims to extend itself to another vibrant and extremely interdisciplinary league of RoboCup@Home. Given that the focus and goals of RoCKIn@Home are on the same lines as of RoboCup@Home, participating in the RoCKIn Competition 2014 would be an ideal opportunity for our team . As a precursor to this, our team had the great chance to participate in the RoCKIn Camp 2014, organized in Rome, Italy, where we not only obtained theoretical and hands-on experience in to this new domain but also showcased our robot's capabilities that eventually led us to receive the award for "Best in Class for Manipulation"[1]. More recently, we participated in the 'FreeBots' league in the Portuguese Robotics Open 2014. As teams are free to choose and demonstrate any robot(s) of their choice in this league, we successfully demonstrated our robot assisting its owner to receive a package (registered or unregistered mail) from a postman by attending the latter at the door. More details regarding this participation can be obtained from our team's homepage[2]. Furthermore, SocRob@Home will also situate itself as a testbed for some of the research developed in the EU-FP7 project MOnarCH, which our university is currently coordinating and where most of our team members are also involved directly. Eventually, in MOnarCH, where the focus is on social robots that interact with children, visitors and staff in a hospital environment, the final SocRob@Home robot will be used as one of the robots.

The broader goals of SocRob include inculcating in young researchers the ability 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.

The rest of the paper is organized as follows. In Section III we describe our research objectives and the goals we envisage through our participation in the @Home-type competitions in general. Section IV provides a detailed description of the robotic platform we intend to use in the @Home-type competitions as well as take to the RoCKIn competition 2014. Towards the end of this paper, in Section V, we provide a summary of the most relevant achievements of our team members.

III. RESEARCH OBJECTIVES AND GOALS

Domestic robotics is a rapidly growing field of research with applications ranging from simple robotic machines 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 not only

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

[2] http://socrob.isr.ist.utl.pt

need to address the issues of sensor-fusion, decision-making and complex manipulations but should also posses a highly natural human-robot interaction skills. Based on our past research experience and skills, we intend to address the sensor-fusion and decision-making problems using the concepts of distributed and networked-robotic systems (NRS). Initially, it will involve a single robot in an NRS with a network of static sensors if available in the environment. Later, this could be extended to a team of mobile robots within an NRS. We further enumerate our research-specific objectives through @Home-type participation.

- ***Perception and Sensor Fusion*:** Our research in this domain includes vision-based robot localization [1], object tracking [2], simultaneous localization and tracking (SLOT) [3], environment modeling [4], laser-based robot localization [5] and, vision-based simultaneous localization and mapping (SLAM) [6].
  Particle filter-based (PF) methods have been the focus of our research to address most perception-related problems. Using PFs, the key issues that we have been engaged in solving includes i) fusion of noisy sensory information acquired by mobile robots where the robots themselves are uncertain about their own poses [1] [2], and ii) scalability of such fusion algorithms w.r.t. the number of robots in the team [3] as well as the number of objects being tracked.
  For a domestic service robot working in a @Home-type environment, localization, mapping and object/person tracking constitute the basic requirements. In addition to this, static sensors along with mobile robots in an NRS, introduce further challenging issues for sensor-fusion algorithms. Considering these, we intend to actively drive-forward our perception-related research in SocRob@Home.
- ***Decision Making*:** In prior work, we have addressed the problem of decision making for teams of autonomous robots, primarily through approaches based on the theory of Discrete Event Systems (DES) [7], [8], [9], and also through decision-theoretic formalisms for multiagent systems (Partially Observable Markov Decision Processes – POMDPs) [10]. Recently, we have bridged these two modeling approaches, through the development and application of event-driven decision-theoretic frameworks [11], [12]. 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 ongoing MultiAgent Surveillance Systems (MAIS+S) project (ref. CMU-PT/SIA/0023/2009), where we have successfully implemented an NRS for autonomous surveillance, comprising a team of mobile mobile robots and a set of stationary cameras. The system is able to automatically detect relevant events in its operational environment, and the robot team can cooperatively decide on the appropriate response. In this context, we have also developed a suite of software tools to aid researchers in the systematic deployment of these abstract, decision-theoretic methodologies on autonomous robots (the Markov Decision Making Library [13]).
  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: 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. Automated dialogue systems, which we also plan to develop as part of our research effort in SocRob@Home, can also be interpreted as partially observable decision making problems.
- ***Manipulation*:** Although we have less experience so far in this area, researchers in our team target the deployment of two robotic arms on our mobile robot platform (detailed in Section IV). Simultaneously, we are also developing motion control algorithms in the full configuration space of the robotic platform and the manipulator.
- ***Human-Robot Interaction*:** We have focused on serviced robots in office environments, addressing in particular symbiotic autonomy: robots execute tasks requested by users, while autonomously aware of their own limitations, asking humans for help the robot overcoming them [14], [15]. More recently we have been moving towards speech-based communication, in order to address the @home requirement of natural human-robot interaction. However, all comunicative acts accessible from voice are also accessible through the robot touchscreen.

IV. ROBOT DESCRIPTION (HARDWARE AND SOFTWARE)

We are currently using a fully self-developed robot called ISR-Cobot, whose driving chassis is a 3-wheeled omnidirectional platform as shown in Fig. 1. On top of it a pedestal supports the main equipment onboard: a laptop with touchscreen for user interface, a fisheye lens-based omnidirectional camera, a Kinect sensor, and a wireless access point along with a 5-DOF Katana Arm. It must also be noted that we are in process of migrating towards one of the 4-wheeled omnidirectional platforms being developed for the FP7 European project MOnarCH [16] as shown later in Fig. 3. In this project, the RoCKIn@Home and RoboCup@Home competitions will be used as one of the test beds. Moreover, being omnidirectional platforms they are capable of deviating from obstacles without changing the robot heading. This is a consequence of their non-holonomy.

On ISR-Cobot we use the robot operating system (ROS) as the middleware to implement all the functional components. Some of the most prominent components are described in the further subsections.

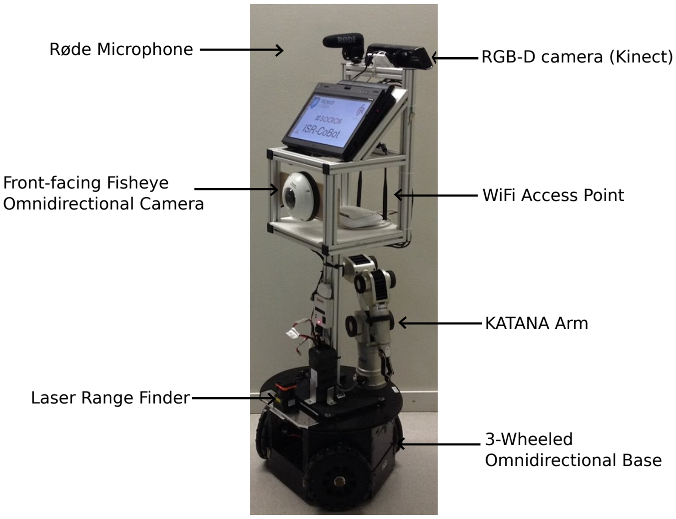

Fig. 1. ISR-Cobot platform with the onboard equipment indicated.

A. 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. We further assume an existing self-localization system, possibly (but not necessarily) based on data fusion of odometry and range sensor matching with the map.

The guidance problem is approached as a two step process. First, given a goal location, the robot plans its path from the current pose to the goal pose. And second, the plan is executed by the robot, in real time, while avoiding unmapped obstacles. These two steps are described in the following two sub-subsections.

For navigation we use a standard occupancy grid map [17], obtained from off-the-shelf SLAM software[3] This map is used both for motion planning, using Fast Marching Method (FMM) [18], and localization, using off-the-shelf software[4]. Guidance and obstacle avoidance relies on a Dynamic Window Approach (DWA) [19], [20] algorithm.

1) Optimal motion planning:: Our path planning is based on a FMM approach [18]. Given a map constraining the workspace of the robot, together with a feasible goal point, a (scalar) potential field $u(x)$, for $x \in R^2$, is constructed such that, given a current robot location $x(t)$, the path towards the goal results from solving the ordinary differential equation $\dot{x}(t) = -\nabla u(x)$. In other words, given an arbitrary current location of the robot x, the robot should follow a gradient descent of the field $u(x)$.

The use of FMM provides: (1) local minima free path to goal across the gradient, (2) allows the specification of a spatial cost function, that introduces a soft clearance to the environment obstacles, and (3) does not require explicit path planning and tracking.

The FMM is based on the Level Set theory, that is, the representation of hypersurfaces as the solution of an equation $u(x) = C$. The solution of the Eikonal equation

$$\begin{aligned} |\nabla u(x)| &= F(x) \\ u(\Gamma) &= 0 \end{aligned} \tag{1}$$

where $x \in \Omega$ is a domain, Γ the initial hypersurface, and $F(x)$ is a cost function, yields a field $u(x)$ [18]. The level sets of this field define hypersurfaces $u(x) = C$ of points that can be reached with a minimal cost of C. The path that minimizes the integral of the cost along the trajectory can be shown to correspond to the solution of $\dot{x}(t) = -\nabla u(x)$ with the initial condition of $x(0)$ set to the initial position and the initial condition $u(\Gamma) = 0$ set at the goal[5]. Intuitively it corresponds to the propagation of a wave front, starting from the initial hypersurface, and propagating with speed $1/F(x)$. FMM is a numerically efficient method to solve the Eikonal equation for a domain discretized as a grid.

Since FMM employs a grid discretization of space, it can be directly applied to the occupancy grid map, where domain Ω corresponds to the free space in the map.

Figure 2 illustrates the results of this approach: the cost function for the given map, allowing a certain clearance from mapped obstacles, is shown in (a), from which, given a goal location, a field $u(x)$, shown in (b) is obtained (the goal corresponds to the minimum value of the field), and in (c) the real path taken by the robot is shown.

2) Guidance and obstacle avoidance:: The goal of guidance is to compute in real time the robot actuation, in terms of motion velocity, given a FMM field $u(x)$ embedding the optimal path to the goal. We solve this problem by taking a Dynamic Window Approach (DWA) [19], [20]. That is, given the robot's current velocity, pose and available sensor data, DWA computes the next motion velocity command. It 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, that is, the robot is unable to stop, at the maximum de-acceleration, in time before hitting an obstacle
4) compute an evaluation value for each candidate by weighting three contributions: (i) progress towards the goal, (ii) clearance from obstacles, and (iii) 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.

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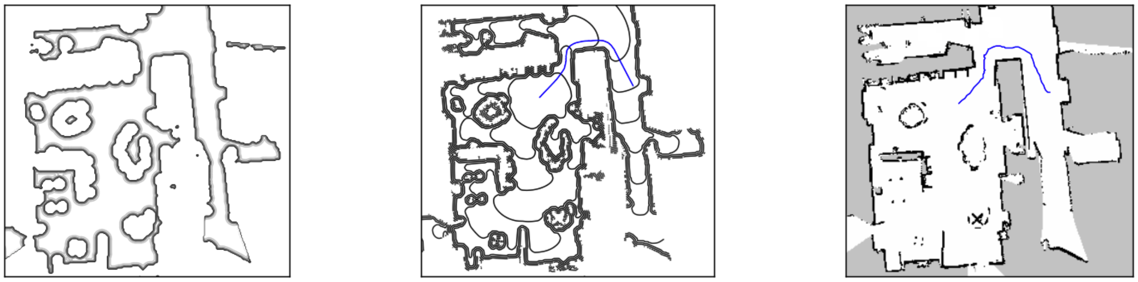
[3] GMapping (`http://wiki.ros.org/gmapping`, retrieved 16-Oct-2013).

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

[5] Γ is set to an arbitrarly small ball around the goal.



(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.

This algorithm follows closely the DWA as initially proposed in [19], 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.

B. Manipulation

We are using a Katana arm model 300 6M180, a 5-DoF manipulator, mounted on the base platform. The arm weight is about 5Kg with a payload of 400g. The Katana drivers available for ROS were slightly modified in order to prevent collision of the arm with the robot body during calibration. 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.

However, we expect to replace this arm by a Robai Cyton Gamma 1500 arm once we migrate to the new 4-wheel omnidirectional platform. This arm is a 7-DoF, and thus it will overcome some limitations of the current one.

C. Interaction with users

Our platform supports two interaction modalities: (1) touch interface over a Graphical User Interface(GUI), and (2) speech synthesis and recognition. Speech interface is currently task-oriented, that is, the dialogue with the user is tailored towards the execution of a specific task. During dialogue, all user response options are also available through the GUI, so that if the robot is unable to recognize the user speech, he(r) can always use the GUI as a backup.

Text-To-Speech (TTS) employs the eSpeak[6] package, while Automatic Speech Recogniton (ASR) is based on Pocketsphinx[7]. Speech understanding is based on the definition of a grammar over a corpus, which spawns the possible sentences the ASR recognizes.

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 into the main FSM to guide the robot behavior accordingly. An example dialogue session follows[8]:

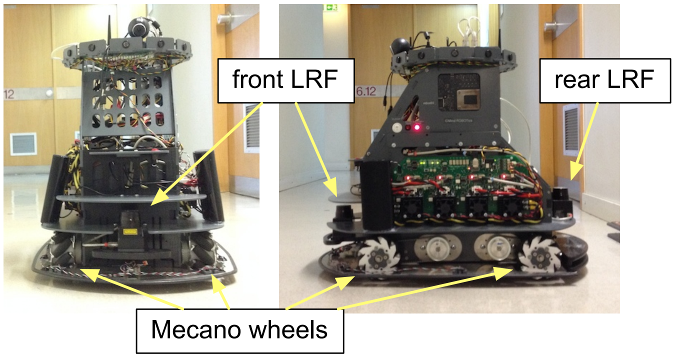


Fig. 3. ISR-Cobot's future navigation platform with laser range finders (LRFs).

Robot — Hello, who's there?
Human— Hello CoBot, I'm the postman
Robot — Did you say that you are the postman?
Human— CoBot, yes
Robot — Hello postman, I am CoBot, have you got something for us?
Human— I have a package for granny
Robot — Did you say that you have a package for granny?
Human— CoBot, yes
Robot — Is it regular or a registered package?
Human— It is a regular package
Robot — Did you say that it is a regular package?
Human— CoBot, yes
Robot — Ok, can I take it?
Human— Yes, please
Robot — Did you say "yes please"?
Human— CoBot, yes
Robot — Ok, give it to me

V. COMPETENCE OF TEAM MEMBERS

The team covers a broad range of competences, from Mecatronics integration to high-level decision making, including

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

[7] http://cmusphinx.sourceforge.net/

[8] http://youtu.be/4mF0_5MCgpw, from 0:15 to 0:53.

perception and navigation. We briefly describe below the competence of each team member:

- Aamir Ahmad is a Post-Doc with a strong background on multi-robot simultaneous localization and tracking. He has a extensive experience in robotic competitions, namely in the SocRob MSL team. He will be supervising all perception activities.
- João Messias is a Post-Doc with a strong background on theoretic decision-making under uncertainty. He also has an extensive experience in the SocRob MSL team. He will be supervising all decision-making activities.
- João Mendes is a grantee that has been involved in the mecatronic integration of various land and aerial vehicles. His previous experience includes the participation in Robot Rescue League competitions. He is responsible for the hardware platform.
- Filipe Jesus is a grantee that has been involved in the Urban Search&Rescue Robots, and in particular on the problem of vision-based SLAM. He also has experience in Robot Rescue League competitions. He will address mapping and software integration activities.
- Diogo Pires is a MSc student, addressing the mapping and navigation modules.
- Pedro Resende is a MSc student with prior experience in the SocRob MSL team. He will be addressing MDP-based human-aware task planning.
- André Farinha is a MSc student with a mechatronic background. He will be involved in the object manipulation problem.
- André Mateus is a MSc student and he will be addressing the person recognition and tracking problems.
- Isabel Ferreira is a Post-Doc with a strong background in linguistics. She is advising the team in what concerns Human-Robot Interaction issues, from a social sciences perspective.
- João Sequeira is faculty, having extensive experience in mobile robotics. He is the coordinator of the MOnarCH project, which has close affinity with the SocRob@Home team. We expect to enjoy strong cross-fertilization among projects.
- Rodrigo Ventura, and Pedro Lima are faculty which have been involved in robot competitions since the first editions of the RoboCup event. They are coordinating the whole team.

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