Preprint of a paper which appeared in:
KI - Künstliche Intelligenz, Vol. 30, No. 3, pp. 311-314, 2016

From RoboCup Rescue to Supervised Autonomous Mobile Robots for Remote Inspection of Industrial Plants

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Received: date / Accepted: date

Abstract With increasing capabilities and reliability of autonomous mobile robots, inspection of remote industrial plants in challenging environments becomes feasible. With the ARGOS challenge, oil and gas company TOTAL S.A. initiated an international competition aimed at the development of the first autonomous mobile robot which can safely operate in complete or supervised autonomy over the entire onshore or offshore production site, potentially in hazardous explosive atmospheres and harsh conditions. In this work, the approach of joint Austrian-German Team ARGONAUTS towards solving this challenge is introduced, focussing on autonomous capabilities. These build on functional components developed during prior participation in the RoboCup Rescue Robot League.

Keywords Urban Search and Rescue · Mobile Robotics · Industrial Inspection · Autonomous Navigation · Supervised Autonomy

Research presented in this paper has been supported within the ARGOS Challenge by TOTAL S.A., within the EUROSTARS Program (Project E!9448 - ATEX Robot Inspection) by the German Federal Ministry of Education and Research (BMBF) and within the Hessian LOEWE initiative by the NICER project.

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1 Introduction

The ARGOS challenge competition [5] has been initiated by TOTAL as a catalyst for the development of the first robot that can be used for supervised autonomous inspection of oil and gas sites with the overall objective to enhance the safety of operators in isolated production sites[1]. Out of 31 proposals from 15 countries, five international teams have been selected in 2014 for funding and participation in the competition. Team ARGONAUTS consists of the Austrian company taurob responsible for the robot's hardware and basic locomotion and teleoperation capabilities, TU Wien responsible for visual perception and TU Darmstadt responsible for autonomous robot capabilities.

Different modes of operation are required. In autonomous operation mode the robot performs routine surveillance rounds over an entire onshore or offshore production site, potentially in hazardous explosive atmospheres and harsh environmental conditions for locomotion and perception as those encountered on offshore rigs and subject to large variations in weather and lightning situations. During these rounds the robot must inspect a number of visual check points, like pressure gauges and valves, and monitor the plant for thermal hot spots, gas leaks and sound signals. A human supervisor shall be able to access the reports and check the robot system status at any time, but no direct intervention is required except if an anomaly is detected.

[1] http://www.agence-nationale-recherche.fr/ARGOS-Challenge

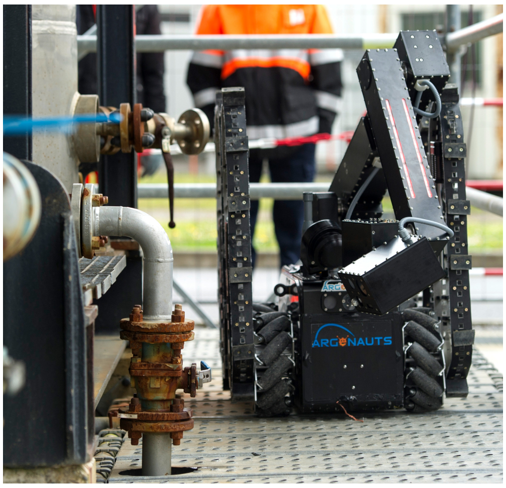

Fig. 1 Current ARGONAUTS robot autonomously inspecting a valve in an industrial plant during the 2nd ARGOS Competition. The sensor arm is used to obtain a close-up view of the object of interest.

In a teleoperated semi-autonomous mode the robotic system must provide the remote operator with situational awareness and the ability to carry out high level commands as well as to provide assistance functions such as anti-collision and energy-level monitoring during motion of mobile robot base and arm. Furthermore, the robot must be able to traverse industrial stairs connecting the multiple floors of the industrial site and to negotiate different types of obstacles. As explosive gases might be present, the robot has to be ATEX certifiable, which presents significant challenges, e.g., to put all sensors (but also actuators and computers) in appropriate housing that might degrade their data quality.

The overall challenges for research and development of such robots deployed on real sites include highly reliable autonomous navigation, robustness of perception and locomotion on grated metal floor and stairs to largely varying outdoor environmental conditions, intelligent reactions to evolving situations, user friendly complex mission programming, robot teleoperation and surveillance modes.

2 Background

Motivated by an aftermath analysis of the 1995 Kobe earthquake, the RoboCup Rescue League (RRL) [7] was introduced in 2001 to address fundamental research and development topics by providing standardized environments and benchmarks for teleoperated and autonomous rescue robots. These tests represent major challenges typically encountered in urban search and rescue (USAR) scenarios. The RRL is supported by the U.S. National Institute for Standards and Technology and develops and applies standard test methods for response robots for systematic evaluation of robot capabilities. Often, test methods are being first introduced in the RoboCup competition and then evolve to become standard test methods [10]. The current RRL competition aims at improving USAR robot capabilities in diverse categories like autonomous capabilities, mapping and mobility. The Japanese USAR robot Quince [12] is one of the few robots which have early been deployed in the heavily damaged Fukushiim Daiichi nuclear power plant. It has been evaluated and improved in RRL before. Team ARGONAUTS builds on Team Hector's expertise and contributions to RRL like an open source framework for autonomous navigation [3].

The middleware ROS (www.ros.org) has become the de-facto standard in the robotics research community and is gaining also significant interest from industry. It has been widely adopted for use in the RoboCup Rescue competition and is also used by Team ARGONAUTS.

Although capabilities of mobile robots relevant to the aforementioned scenario have been considered in recent years, their integration into a single robotic system reliably performing complex missions under realistic conditions and in different autonomy modes is yet to be shown. Relevant approaches for basic robot capabilties have been made available by other researchers as ROS packages. These provide a number of basic building blocks for autonomous mobile robots. For the project, the navigation stack [6], the MoveIt! motion planning system [1] and the grid map library [2] have been positively evaluated and are used within the project.

3 Robot Platform

A dedicated robot platform has been developed by our partner taurob Gmbh to meet the requirements of the ARGOS Challenge (Fig. 1). The current robot is fully symmetric and the driving direction can be reversed instead of turning around in narrow environments. Spinning LIDARs for full 3D environment perception are mounted both in the front and rear. It uses tracked wheels, so-called flippers, for locomotion and carries an arm with a multi-modal sensor head.

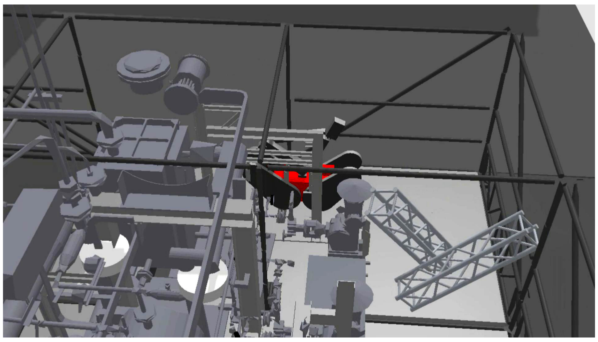

Fig. 2 Simulation of test site and robot mission in Gazebo. For testing autonomous reactions, metal trusses simulating damage to the structure of the site have been added.

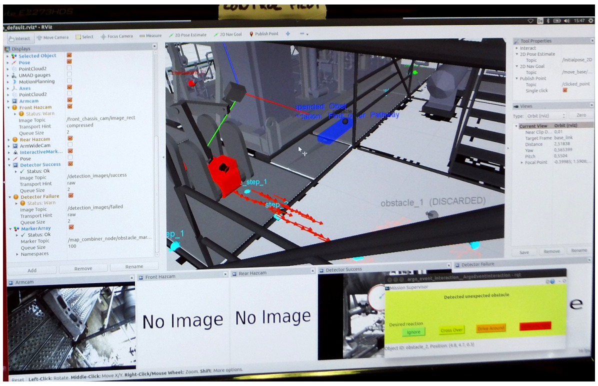

Fig. 3 Screenshot of operator control station at detection of an unknown obstacle: The detected obstacle is overlaid over the 3D model of the site in the 3D view. In the lower left, the view from the camera in the sensor head shows the obstacle, a cinder block, as the arm was automatically moved to look at the detected obstacle. On the lower right, a widget notifying the operator is shown. Images of the front and rear cameras at the robot's base are not displayed here.

4 Autonomy

In this section, key aspects of the autonomous robotic system are described.

Simulation. In presence of tight constraints for development time and the need for simultaneous development of hard- and software, the ability to perform testing on a virtual, but realistic, test site and rapid prototyping is crucial for system integration and evaluation. The capability for full system testing in simulation was realized using the Gazebo simulator. This enables the full system including simulation of physics and all sensor data being tested on dedicated or personal computers of members of the team (cf. Fig. 2).

Localization. Unlike the USAR disaster scenario in RRL, the site encountered in the ARGOS challenge is previously known (besides potential local structural changes). This is leveraged to increase reliability of localization, by localizing the robot within a 3D map generated offline. As the map used for localization is not updated in real-time the risk of map corruption in case of temporary faulty localization is eliminated. While the *hector_slam* [4] approach developed during participation in RoboCup Rescue has been proven to work reliably also in industrial scenarios, the 2D map representation employed there does not support 6DOF localization during stair climbing. For this reason, the *ethzasl_icp_mapper* [8] package is utilized instead.

Environment monitoring. The inspection task also includes monitoring the environment for hazards such as heat sources or changes relative to the previously known model of the site. For detection of heat sources, the same approach developed for the RRL is employed, using a thermal camera scanning the environment for heat sources. Once a source is detected, the behavior control system is notified and an inspection routine executed that moves the sensor am into an inspection pose for determining heat source temperature and pose.

Two approaches are developed for monitoring for changes in the environment: Planned paths can be queried for obstacles that lie within the footprint covered by the path (cf. Fig. 3). Hereby, computation is only performed highly efficient and on demand. The other option is an exhaustive search of the environment around the robot comparing the prior map of know free space to a elevation map generated from sensor data in real-time.

Path Planning. The narrow spaces of oil and gas sites provide significant challenges for navigation of mobile robot base and arm. An adapted version of the exploration motion planner developed within the scope of RRL is used in pure goal planning mode. Based on the exploration transform algorithm, it allows for generating plans that maximize the distance of the robot to obstacles for all poses on a planned path. Due to the previously mentioned symmetric robot design, full rotations of the robot can be avoided.

Arm Motion Planning. For flexible inspection and monitoring abilities, sensors are mounted on the end effector of a manipulator arm. With the narrow spaces on oil and gas sites, this allows for a wide range of inspection poses for sensors, despite mobility of the robot platform being limited by the environment. To allow for safe, collision free operation, the 3D model of the environment based on the OctoMap [11] library is utilized during motion planning. Using a reachability planning approach, observation poses for a given object pose are generated automatically. This significantly increases robustness, as failed detection attempts can easily be retried from dynamically generated alternative camera poses.

Stair Traversal. The capability to safely and reliably traverse stairs is a necessity on many industrial installations. The same capability has been demonstrated to be highly relevant in a disaster reponse context, for instance at the reconnaisance operations at the Fukushima-Daiichi nuclear plant [12]. For application in disaster environments, an approach for the traversal of stairs based on on-line sensor data has been developed. For the ARGOS challenge scenario, the location and shape of the stairs is previously known, obviating the need to detect stairs in sensor data. However, unknown obstacles must also be detected and negotiated.

Mission Programming and Behavior Control. For control of high level behavior and interfacing basic robot capabilities, the Flexible Behavior Engine (FlexBE) approach has been developed [9]. Using automated behavior synthesis, missions to visit multiple checkpoints in the environment can be specified by using a simple comma separated string expression. The development of a capable user interface for quick and fail safe mission programming and adaption is still an open issue.

5 Summary

The approach of Team ARGONAUTS for supervised highly mobile autonomous robots for remote monitoring of plants in explosive atmospheres has been prestend, which builds on prior developments for USAR robots achieved by Team Hector within the RRL.

In the ARGOS Challenge, in total three competitions are foreseen. Team ARGONAUTS achieved overall 2nd ranks in the first and second competition in June 2015 and April 2016, respectively. The third and final competition will be held in March 2017. Each competition consists of several functional as well as mission oriented runs with increasing complexity and difficulty on a real test site. Here, the evaluations are strongly driven from enduser interests and perspective whereas in RRL they are driven mainly by functional requirements.

Acknowledgements The authors gratefully acknowledge the contributions by and fruitful cooperation with all members of Teams ARGONAUTS and Hector.

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