ToBI - Team of Bielefeld The Human-Robot Interaction System for RoboCup@Home 2015

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Abstract. The Team of Bielefeld (ToBI) has been founded in 2009. The RoboCup activities are embedded in a long-term research history towards human-robot interaction with laypersons in regular home environments. The RoboCup@Home competition is an important benchmark and milestone for this goal in terms of robot capabilities as well as the system engineering approach. For RoboCup 2015, we focus on two different aspects. First, mainly improved abilities for the perception-based understanding of the robot's environment. An Articulated Scene Model (ASM) is used to systematically fuse scene change events with the perception of the 3D room structure. This information is used to adopt the robot's behavior to the current situation. Another focus is the interaction with multiple mini robots to solve a complex task.

1 Introduction

The RoboCup@Home competition aims at bringing robotic platforms to use in realistic home scenarios. Thus, the robot needs to deal with unprepared domestic environments, perform autonomously in them and interact with laypersons.

Todays robotic systems obtain a big part of their abilities through the combination of different software components from different research areas. To be able to communicate with humans and interact with the environment, robots need to coordinate their components generating an appropriate overall robot behavior that fulfills parallel goals of gathering scene information, achieving a task goal, communicate their internal status, and being always responsive to humans. This is especially relevant for complex scenarios in domestic settings.

Team of Bielefeld (ToBI) has been founded in 2009 and successfully participated in the RoboCup German Open from 2009-2014 as well as the RoboCup World Cup from 2009-2014. The robotic platform and software environment has been developed based on a long history of research in human-robot interaction [1–3]. The overall research goal is to provide a robot with capabilities that enable interactive teaching of skills and tasks through natural communication in previously unknown environments. The challenge is two-fold. On the one hand, we need to understand the communicative cues of humans and how they interpret robotic behavior [4]. On the other hand, we need to provide technology that is able to perceive the environment, detect and recognize humans, navigate in changing environments, localize and manipulate objects, initiate and understand a spoken dialog and analyse the different scenes to gain a better understanding of the surrounding.

Another focus of the system is to provide an easy to use programming environment for experimentation in short development-evaluation cycles. We further observe a steep learning curve for new team members, which is especially important in the RoboCup@Home context. The developers of team ToBI change every year and are Bachelor or Master students, who are no experts in any specific detail of the robot's software components. Therefore, specific tasks and behaviors need to be easily modeled and flexibly coordinated. In concordance with common robotic terminology we provide a simple API that is used to model the overall system behavior. To achieve this we provide an abstract sensor- and actuator interface (BonSAI) [5] that encapsulates the sensors, skills and strategies of the system and provides a SCXML-based [6] coordination engine.

2 The ToBI Platform

The robot platform *ToBI* is based on the research platform *GuiaBot*$^{\text{TM}}$ by adept/mobilerobots[1] customized and equipped with sensors that allow analysis of the current situation. ToBI is a consequent advancement of the *BIRON* (**BI**elefeld **R**obot compani**ON**) platform, which is continuously developed since 2001 until now. It comprises two piggyback laptops to provide the computational power and to achieve a system running autonomously and in real-time for HRI.

The robot base is a PatrolBot$^{\text{TM}}$ which is 59cm in length, 48cm in width, weighs approx. 45 kilograms with batteries. It is maneuverable with 1.7 meters per second maximum translation and 300+ degrees rotation per second. The drive is a two-wheel differential drive with two passive rear casters for balance. Inside the base there are two 180 degree laser range finders with a scanning height of 30cm above the floor (SICK LMS in the front + Hokuyo UBG-04LX in the back), see Fig.1 bottom right). For controlling the base and solving navigational tasks, we rely on the ROS navigation stack[2].

In contrast to most other PatrolBot bases, ToBI does not use an additional internal computer. The piggyback laptops are Core i7 © (quadcore) processors with 8GB main memory and are running Ubuntu Linux. For person detection/recognition we use a full HD webcam of the type Logitech HD Pro Webcam C920. For object recognition we use a 24MP DSLM camera (Sony Alpha α6000).

For room classification, gesture recognition and 3D object recognition ToBI is equipped with an optical imaging system for real time 3D image data acquisition, one facing down (objects) and an additional one facing towards the

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[1] www.mobilerobots.com

[2] `http://wiki.ros.org/navigation`

user/environment. The corresponding computer vision components rely on implementations from Open Source libraries like OpenCV[3] and PCL[4].

Additionally the robot is equipped with the Katana IPR 5 degrees-of-freedom (DOF) arm (see Fig.1); a small and lightweight manipulator driven by 6 DC-Motors with integrated digital position encoders. The end-effector is a sensor-gripper with distance and touch sensors (6 inside, 4 outside) allowing to grasp and manipulate objects up to 400 grams throughout the arm's envelope of operation.

To improve the control of the arm, the inverse kinematics of the Katana Native Interface (KNI) was reimplemented using the Orocos [7] Kinematics and Dynamics Library (KDL)[5]. This allowed further exploitation of the limited workspace compared to the original implementation given by the vendor. This new implementation also enables the user to use primitive simulation of possible trajectories to avoid obstacles or alternative gripper orientations at grasp postures, which is important due to the kinematic constraints of the 5 DoF arm.

The on-board microphone has a hyper-cardioid polar pattern and is mounted on top of the upper part of the robot. For speech recognition and synthesis we use the Open Source toolkits CMU Sphinx[6] and MARY TTS[7]. The upper part of the robot also houses a touch screen ($\approx 15in$) as well as the system speaker. The overall height is approximately 140cm.

Fig. 1. ToBI with its components: camera, 3D sensors, microphone, KATANA arm and laser scanner.

3 Reusable Behavior Modeling

For modeling the robot behavior in a flexible manner ToBI uses the *BonSAI* framework. It is a domain-specific library that builds up on the concept of *sensors* and *actuators* that allow the linking of perception to action [8]. These are organized into robot *skills* that exploit certain *strategies* for an informed decision making.

We facilitate *BonSAI* in different scenarios: It is used for the robot BIRON which serves as a research platform for analyzing human-robot interaction [4] as well as for the RoboCup@Home team ToBI, where mostly unexperienced students need to be able to program complex system behavior of the robot in a short period of time. In both regards, the *BonSAI* framework has been improved

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[3] `http://opencv.org/`

[4] `http://pointclouds.org/`

[5] `http://www.orocos.org/kdl`

[6] `http://cmusphinx.sourceforge.net/`

[7] `http://mary.dfki.de/`

such that system components are further decoupled from behavior programming and the degree of code re-use is increased.

To support the easy construction of more complex robot behavior we have improved the control level abstraction of the framework. *BonSAI* now supports modeling of the control-flow, as e.g. proposed by Boren [9], using State Chart XML. The coordination engine serves as a sequencer for the overall system by executing *BonSAI skills* to construct the desired robot behavior. This allows to separate the execution of the skills from the data structures they facilitate thus increasing the re-usability of the skills. The *BonSAI* framework has been released under an Open Source License and is available online[8].

4 Spatial Awareness

ToBI builds up different kinds of spatial representations of its environment using 2D and 3D sensors. This improves the robot's situation awareness and supports its searching abilities. In our *Articulated Scene Model* approach, we systematically deal with these aspects and present a method to generate a scene model of a system's current view incorporating past egocentric views by utilizing self-motion and allocentric representations [10]. Thereby, we enhance the current egocentric view of the robot to better deal with perception tasks like segmentation or reference resolution. Vice versa allocentric representations are enriched by semantic information extracted from egocentric views for more sophisticated navigation and localization [5].

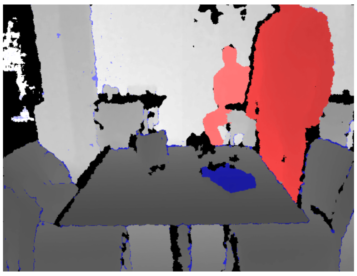

Fig. 2. Example for the Articulated Scene Model. Red: Dynamic. Blue: Movable

4.1 Articulated Scene Model

As a basis for the presented approach we use the *Articulated Scene Model* (ASM) introduced by Swadzba *et al.* [11]. This model enables an artificial system to categorizes the current vista space into three different layers: The *static background* layer which contains those structures of the scene that ultimately limit the view as static scene parts (e.g. walls, tables); second, the *movable objects* layer which contains those structures of the scene that may be moved, i.e. have a background farther perceived after moving (e.g. chairs, doors, small items); and third, the *dynamic objects* layer which contains the acting, continiously moving agents like humans or robots. An example is depicted in Fig. 2. In the application for our robot ToBI, we focus on detection of completed scene changes which involves a comparison of currently visible structures with a representation in memory.

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[8] `http://opensource.cit-ec.de/projects/bonsai`

Hence, our approach detects movable parts and adapts the static background model of the scene simultaneously. The detection of dynamic object parts (like moving humans) is modeled in a separate layer and requires a tracking mechanism. For the implementation in the presented system, the body tracking algorithms in the NiTE Middleware[9] in combination with the OpenNI SDK[10] was used. An extension by Ziegler *et al.* [10] enables the ASM algorithm to detect scene changes by memorizing a scene and use them from another view point.

4.2 Articulated Scene Based Planning

The acquired information from the *Articulated Scene Model* (4.1) are embedded into a 3d scene (Fig. 3). Information on movable as well as static objects is added to a semantic map layer by letting a robot observe a scene. Robots have to be enabled to separate unscalable walls from articulated obstacles in the scene to provide navigation behaviors that are more transparent to a human user. Thus, without pre-labelling scene elements like doors the robot will be enabled to learn from observation and improve its cooperation capabilities.

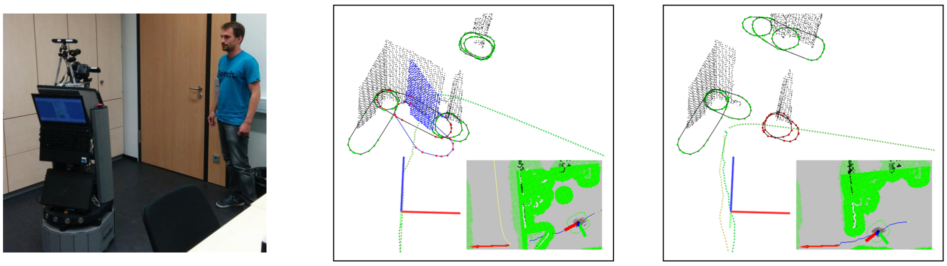

Fig. 3. Relating the articulated door to allocentric information of the 2D map for situated navigation.

A framework for handling exceptional events can be used to improve the robot's behavior by incorporating additional knowledge. The charts in Fig. 4 give an example for a more sophisticated behavior where the path of the robot gets blocked while it navigates to the target. Thus navigation can be treated in a situation specific manner involving an indepth semantic analysis only if needed. This keeps the behavior design simple and modular.

5 AMiRo - Autonomous Mini Robot

To extend and enhance the capabilities of ToBI, the Autonomous Mini Robot (AMiRo) [12] is used in numerous tasks. AMiRo, as can be seen Fig. 5, was

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[9] `http://www.openni.org/files/nite/`, accessed 2014-02-06

[10] `http://www.openni.org/openni-sdk/`, accessed 2014-02-06

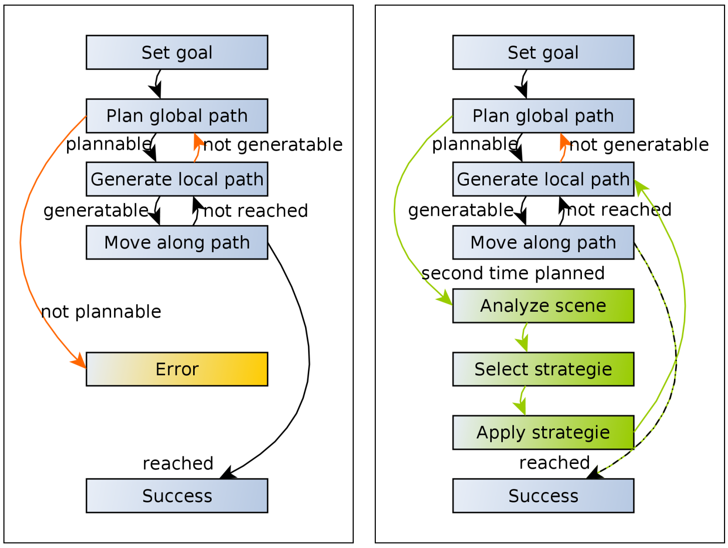

Fig. 4. Left: typical navigation strategy with obstacle avoidance; right: adaptive strategy for more sophisticated navigation based on semantic scene information.

developed at Bielefeld University with the main objective of research and education. It consists of set of electronic modules for sensor processing, actuator control and cognitive processing that fully utilise currently available electronics technology for the construction of mini robots capable of rich autonomous behaviours. All mechanical parts for the robot are off-the-shelf components or can be fabricated with common drilling, turning and milling machines. The connection between the modules is well defined and supports standard interfaces from parallel camera capture interfaces down to simple serial interfaces.

5.1 The AMiRo Platform

The AMiRo is a two wheeled robot with differential kinematic which physical cylindrical shape was original intended to meet the rules of the AMiRESot robot soccer league [13]. The inside of this shell has to accommodate the power source (batteries), sensors, actuators (motors and wheels) and the computing hardware. Following the principle of functional modularisation the computing hardware consists of several AMiRo modules (AMs) with a prescribed common electronic interface. Each AM is hosted on its own circuit board and contains its own processing unit that can be a microcontroller, a powerful processor or a programmable device. The modules interconnect through two connector pairs mounted on the circuit boards. Each pair has the female connector on the top of the board and the male connector on the underside, such that boards can be plugged into each other to make a stack of boards. Corresponding connector pins on the top and bottom of the boards connect through the board creating a common signal bus for the modules.

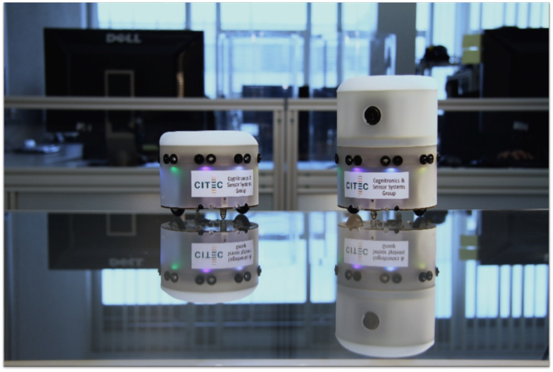

Fig. 5. Autonomous Mini Robot (AMiRo) in two different version. Left: Basic Robot. Right: Mounted Kamera Tower

5.2 Utilization in the RoboCup@Home League

In the RoboCup@Home scenario multiple AMiRos are applied in conjunction with ToBI to build a multi robotic setup which is interconnected via wifi. To build a reliable and fail-safe wifi interoperability between all devices, the Spread Toolkit[11] is applied which is used by a common RSB intercommunication.

Since AMiRo is restricted in environmental manipulations, it can sense its environment with VCNL4020 proximity and ambient light sensor, a ov5647 QSXGA camera and a differential microphone pair to build up a distributed sensor system for ToBI. Additionally AMiRo can be equipped with any USB or serial device to extend its sensor and actor capabilities. To name one extension, the Hokuyo URG04-LX was mounted on the AMiRo which was used by the a CoreSLAM[12] implementation for simultaneous localization and mapping.

6 Conclusion

We have described the main features of the ToBI system for RoboCup 2015 including sophisticated approaches for utilizing semantic information of 3D scenes. BonSAI represents a flexible rapid prototyping environment, providing capabilities of robotic systems by defining a set of essential skills for such systems. The underlying RSB middleware allows to extend it even to a distributed sensor network, here, defined by multiple mini-robots. The RoboCup@HOME competitions in 2009 to 2014 served for as a continuous benchmark of the newly adapted platform and software framework. Especially BonSAI with its abstraction of the robot skills proved to be very effective for designing determined tasks, including more script-like tasks, e.g. 'Follow-Me' or 'Who-is-Who', as well as more flexible tasks including planning and dialog aspects, e.g. 'General-Purpose-Service-Robot' or 'Open-Challenge'.

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[11] `http://spread.org/`

[12] `https://www.openslam.org/tinyslam.html`, accessed 2015-02-18

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