ToBI - Team of Bielefeld The Human-Robot Interaction System for RoboCup@Home 2016

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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 2016, we introduce a second platform, the MekaBot M1 which is operated with the same abstract behavior modeling framework. With these two platforms, we focus on more sophisticated mechanisms for robot coordination. This includes a deeper semantic analysis of the situation. In navigation the robot considers different cases of unexpected events, e.g. a previously open door is shut or a person is blocking the way, and acts appropriately. In grasping the system analyses the shape of an object in order to select an appripriate grasping pose. Further, we explore the coordination and interaction of the service robot with multiple mini robots. These are introduced as multi-purpose sensor-actor components in a smart home and allow to solve more complex tasks where the service robot is not in reach.

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 2009-2015 as well as the RoboCup World Cup from 2009-2015. 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 [5].

Another focus of the system is to provide an easy to use programming and deployment environment for experimentation in short development-evaluation cycles. We use a toolchain defined in the Cognitive Interaction Toolkit (CITK) [6] which supports the aggregation of required system artifacts, an automated software build and deployment, as well as an automated testing environment. The communication between software components is based on the Robotic Service Bus (RSB) [7] which provides an API which abstracts from different transports and integrates well with ROS-based nodes.

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) [8] that encapsulates the sensors, skills and strategies of the system and provides a SCXML-based [9] coordination engine. We observe a steep learning curve for new team members, which is especially important in the RoboCup@Home context. This framework also enabled the team to fastly transfer robotic skills from the established ToBI platform to the Meka M1 robot which is newly adapted for the RoboCup@Home competition in this year and provides more sophisticated grasping skills.

2 The ToBI Platform

The robot platform *ToBI* is based on the research platform *GuiaBot*™ 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™ 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

[1] www.mobilerobots.com

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 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.

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[5] and MARY TTS[6]. 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 The Meka Platform

The Meka M1 Mobile Manipulator robotic-platform is part of the CITEC Research Apartment. It is used in the Cognitive Service Robotics Apartment (CSRA)

[2] `http://wiki.ros.org/navigation`
[3] `http://opencv.org/`
[4] `http://pointclouds.org/`
[5] `http://cmusphinx.sourceforge.net/`
[6] `http://mary.dfki.de/`

project[7] to explore research questions related to human-robot-interaction in smart-home environments.

The robot features multiple cameras, a laser range finder and microphones allow to gather information from the environment. A real-time-enabled computer controls the compliant force controlled actuators with four-fingered hands. An omni-directional base and lift-controlled torso enables navigating in complex environments. In total, the robot is equipped with 37 motor-powered joints. It has 7 per arm, 5 per hand, 2 in the head, 2 in the torso and 9 joints actuate the base including the z-lift. The motors in the arms and hands are Series Elastic Actuators (SEAs)[10], which enable fine force sensing.

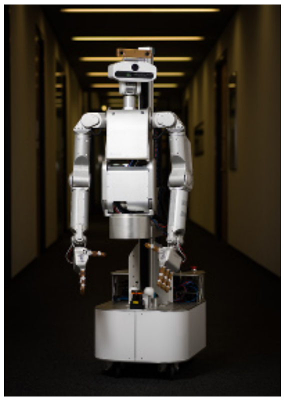

Fig. 2. The meka robot platform

An attention coordination component selects targets for the active camera head. This is based on mixture of bottom-up cues and top-down task requirements. Thereby, the robot is looking for faces as well as salient points in the scene. In case of grasping the attention is guided to a potential planar surface in front of the robot. The grasping strategy is described in more detail in the next section.

4 Flexible Grasping considering object shapes

The previous grasping pipeline involved a basic grasp generator producing many potential grasp poses (up to thousands) around a given center pose of the target object. The number of generated grasp poses was implicitly determined by an equidistant sampling around the camera-aligned bounding box of the object's point cloud, i.e. neither shape nor orientation of the object were considered. All potential grasps were fed into the MoveIt! planning pipeline to check for feasibility. The first adequate grasp pose was finally selected for grasping.

In order to improve the pipeline, both in speed and precision, a new grasp generator was adapted [11]. The grasp generator is composed of two nodes, an object fitting node and a grasp generation node.

A preprocessed point cloud alongside additional information regarding the recognized type of object(s) is generated by the *Classificiation Fusion (CLAFU)* [12] component. It serves the training and recognition of objects in a scene. In training mode, multiple classifiers can be connected in series to learn objects given

[7] https://www.cit-ec.de/de/content/cognitive-service-robotics-apartment-ambient-host

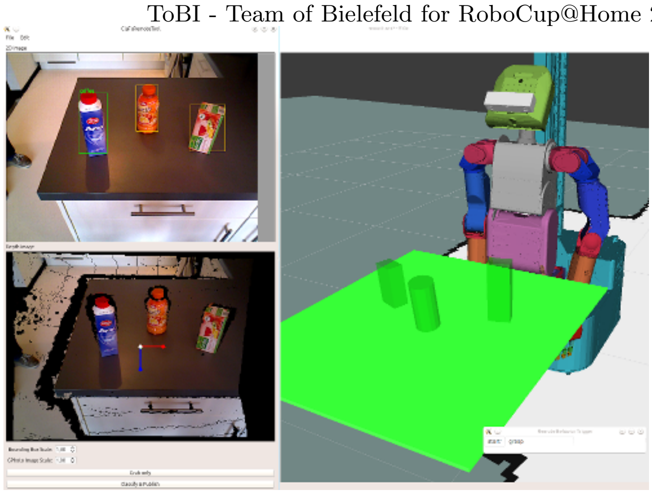

Fig. 3. The grasping pipeline. On the left output of the CLAFU component is displayed. The RVIZ environment including the mobi robot, the detected planar surface as well as fitted superquadric are visible in green.

their 2D- or 3D-features (exemplary classifiers are *SVM*, *Decision Tree* and *KNN*. Available features are e.g. *GIST*, *ColorSHOT* and *FPFH*). Based on the training set, newly encountered objects are classified and beside the current camera and table position forwarded to the fitting node which fits superquadrics into the point cloud. Considered shapes are boxes, spheres and cylinders, that are object aligned.

The grasp generator analytically generates a set of grasp poses exploiting the shape information and object dimensions. For a box, grasps will be aligned to opposing faces; for cylinders and spheres, the arm will approach from the most comfortable direction and thus resolve the redundancy introduced by the shape's symmetry. The grasps will be filtered for feasibility and collision with the table exploiting the object's and hand's bounding boxes.

All remaining grasps are ranked according to several criteria, including preference for side vs. top grasp, comfort/reachability, and motion distance of the hand. Thus, only a reduced set of 1 to 10 grasps per object is fed into the MoveIt! [13] planning pipeline for a final feasibility check, determining a collision-free grasp trajectory.

5 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 [14]. 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 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* supports modeling of the control-flow, as e.g. proposed by Boren [15], 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].

6 AMiRo - Autonomous Mini Robot

To extend and enhance the capabilities of ToBI, the Autonomous Mini Robot (AMiRo) [16] is used in numerous tasks. AMiRo, as can be seen Fig. 4, was 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.

6.1 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 [17]. 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.

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

Fig. 4. Autonomous Mini Robot (AMiRo) in two different version. Left: Basic Robot. Right: Mounted Kamera Tower

6.2 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[9] 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[10] implementation for simultaneous localization and mapping.

7 Conclusion

We have described the main features of the ToBI system for RoboCup 2016 including sophisticated approaches for object grasping. 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. We further show the implementation of the overall framework for different robot platforms, like the GuiaBot or Meka M1. The RoboCup@HOME competitions in 2009 to 2015 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'.

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

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

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8 Team information

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Description of hardware:
- GuiaBot by adept/mobilerobots (cf. section 2)
- Meka M1 by Meka Robotics/Google (cf. section 3)
- AmiRo (cf. section 3)

Description of software:
Most of our software and configurations is open-source and can found at the *Central Lab Facilities GitHub* [11]

Operating System	Ubuntu 14.04 LTS
Middleware	ROS Indigo; RSB 0.12 [7]
SLAM	ROS Gmapping
Navigation	ROS planning pipeline
Object Recogntition	Classificiation Fusion (CLAFU) [12]
People Detection	strands perception people [12]
Behavior Control	BonSAI with SCXML
Attention	Hierachical Robot-Independent Gaze Arbitration [13]
Speech Synthesis	Mary TTS
Speech Recogntition	PocketSphinx with context dependent ASR

[11] `https://github.com/CentralLabFacilities`
[12] `https://github.com/strands-project/strands_perception_people`
[13] `https://github.com/CentralLabFacilities/simple_robot_gaze`