ToBI - Team of Bielefeld
A Human-Robot Interaction System for RoboCup@Home 2017

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Abstract. The Team of Bielefeld (ToBI) has been founded in 2009. The RoboCup teams' activities are embedded in a long-term research agenda towards human-robot interaction with laypersons in regular and smart 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 integration effort. In order to achieve a robust and stable system performance, we apply a systematic approach for reproducible robotic experimentation including automatic tests. For RoboCup 2017, we plan to enhance this approach by simulating complete RoboCup@Home tasks. We further extend it to the RoboCup@Home standard platform *Pepper*. Similar to the Nao platform, the Pepper comes with its own runtime and development eco-system. Thus, one of the challenges will be the cross-platform transfer of capabilities between robots based on different eco-system, e.g. the utilized middleware and application layers. In this paper, we will present a generic approach to such issues: the *Cognitive Interaction Toolkit*. The overall framework inherently supports the idea of open research and offers direct access to reusable components and reproducible systems via a web-based catalog. A main focus of research at Bielefeld are robots as an ambient host in a smart home or for instance as a museum's guide. Both scenarios are highly relevant for the RoboCup@Home standard platform competition. Skills developed in these domains will be transferred to the RoboCup@Home scenarios.

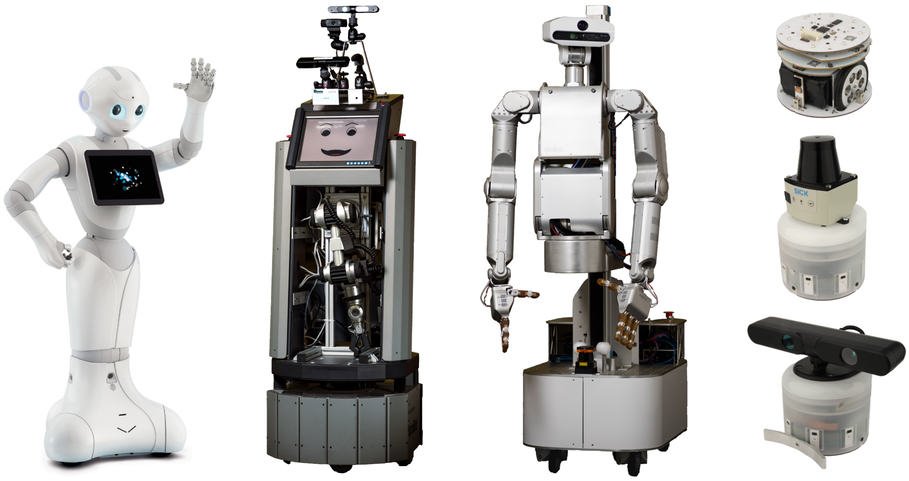
1 Introduction

The RoboCup@Home competition aims at bringing robotic platforms to use in realistic domestic environments. Today's 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 and dynamically configure their components in order to generate an appropriate overall robot behavior that fulfills parallel goals such as 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.

The Team of Bielefeld (ToBI) was founded in 2009 and successfully participated in the RoboCup German Open as well as the RoboCup World Cup from 2009 to 2016. In 2016, the team ended first in several of the individual tests (Navigation, Person Recognition, GPSR, EE-GPSR, Restaurant) and, finally, won the global competition [1]. Bielefeld University is involved in research on human-robot interaction for more than 20 years especially gaining experience in experimental studies with integrated robotic systems [2, 3]. An important lesson learned is that the reproducibility of robotic systems and their performance is critical to show the incremental progress – but that this is rarely achieved [4]. This applies to experimentation in robotics as well as to RoboCup. A Technical Description Paper (e.g. [5]) – as typically submitted to RoboCup competitions – is by far not sufficient to describe or even reproduce a robotic system with all its artifacts. The introduction of a systematic approach towards reproducible robotic experiments [6] has been turned out as a key factor to maximally stabilize basic capabilities like, e.g., navigation or person following. Together with appropriate simulation engines [7] it paves the way to an automated testing of complete RoboCup@Home tasks. The *Cognitive Interaction Toolkit* provides a framework that allows to describe, deploy, and test systems independent of the underlying ecosystem. Thus, the concepts apply for ROS-based components and systems as well as for those defined with, e.g., NAOqi. Combined with an appropriate abstraction architecture, a reusability of components and behaviors can be achieved across platforms. In the Open Challenge and the Final of 2016, we introduced a multi-robot collaboration scenario that combines small mobile sensor devices with human-sized service robots demonstrating the scalability of the communication [8] and behavior [9] framework. This already showed that we are able to deal with cross-platform capabilities. Multi-robot scenarios are becoming more and more attractive for the @home domain, because there is an increasing number of intelligent devices in regular smart homes.

The CITK framework has already been applied on the Nao platform.[1] Research using the Nao utilizes strategies for guiding the focus of attention of human visitors in a museum's context [10]. For this purpose the robot needs to follow the gaze of humans as well as provide referential behaviors. Further strategies are explored in a project that combines service robots with smart environments [11], e.g. the management of the robot's attention in a multi-user dialogue [12]. For the RoboCup@Home Pepper competition we further work on appropriate simulation approaches that allow to easily switch between the real hardware and a simulated environment including virtual sensors and actors. In order to keep our cross-platform approach, we utilized the MORSE Simulation framework [13] that additionally offers extended possibilities for modelling virtual human agents for testing human-robot interaction scenarios [14].

[1] `https://toolkit.cit-ec.uni-bielefeld.de/systems/versions/nao-minimal-nightly`



(a) Pepper (b) Biron (c) Floka (d) AMiRo

Fig. 1. Robotic platforms of ToBI. Pepper is $120cm$ tall, the overall height of Biron is $\approx 140cm$. The Floka platform has an adjustable height between $\approx 160cm$ and $\approx 200cm$. The AMiRo has a diameter of $10cm$.

2 Robot Platforms

In 2016, ToBI participated in RoboCup@Home with the two service robots Biron and Floka. Those were assisted by multiple instances of the smaller AMiRo as an extended mobile sensor platform. Figure 1 gives an overview of the three mentioned platforms together with Pepper as a new platform. We aim at the development of platform independent as well as multi-platform robot capabilties. Nevertheless, each platform has different actuators and sensors.

The Social Standard Platform Pepper (cf. Fig. 1(a)) is newly introduced to the RoboCup@Home competition. It features an omnidirectional base, two ultrasonic and six laser sensors. Together with three obstacle detectors in his legs, these provide him with navigation and obstacle avoidance capabilities. Two RGB cameras, one 3D camera, and four directional microphones are placed in his head. It further possesses tactile sensors in his hands for social interaction. A tablet is mounted at the frontal body and allows the user to make choices or to visualize the internal state of the robot. In our setup we use an additional laptop as a external computing resource which is connected to the onboard computer of the Pepper via Wi-Fi.

The robot platform Biron (cf. Fig. 1(b)) is based on the research platform GuiaBot by adept/mobilerobots, customized and equipped with sensors that allow analysis of the current situation. The Biron platform has been continuously developed since 2001 and has been used in RoboCup@Home since 2009. Its base has a two-wheel differential drive and two laser range finders for localization, navigation, and mapping. Two Asus Xtion PRO LIVE Sensors on top of the base provide RGBD data for sensing obstacles, and graspable objects. For person detection/recognition we additionally use a full HD webcam of the type Logitech HD Pro Webcam C920. For object recognition we use a 24 mega pixel DSLM camera (Sony Alpha α6000). As microphones two Sennheiser MKE 400 are installed front- and back-facing, supported by two AKG C 400 BL on the sides. While the frontal microphones are used for speech recognition, the others are only used for speaker localization. Additionally, the robot is equipped with the Neuronics Katana 450 arm

The following two robots will not be used at the RoboCup@Home 2017 competition. Nevertheless, they were used in previous competitions and demonstrate our platform independent and cross-platform approach. The Floka robot has several elements (omnidirectional base, two arms, lift-controlled torso) that are also featured in the Pepper platform. For human-robot interaction, the small AMiRos required a WiFi connection to an external computing resource. Similar concepts are now used for the Pepper platform.

Our robot Floka (cf. Fig. 1(c)) is based on the Meka M1 Mobile Manipulator robotic-platform [1]. An omni-directional base with Holomni's caster-wheels and a lift-controlled torso enable navigating in complex environments. In total, the robot has 37 DoF, which break down to joints. It has 7 per arm, 5 per hand, 2 for the head, 2 in the torso, and 9 joints actuate the base including the z-lift. The motors in the arms, torso and hands are Series Elastic Actuators (SEAs), which enable force sensing. The sensor-head contains an RGBD and color camera.

The AMiRo (cf. Fig. 1(d)) as used in RoboCup@Home is a two wheeled robot with a physical cylindrical shape [15]. It extends and enhances the capabilities of mobile service robots. Commonly, multiple AMiRos are applied in conjunction to build a multi-robotic setup which is interconnected via Wi-Fi. Each one consists of a set of stackable electronic modules for sensor processing, actuator control, and behavior coordination.

3 System Architecture

Our service robots employ distributed systems with multiple clients sharing information over network. On these clients there are numerous software components written in different programming languages. Such heterogeneous systems require abstraction on several levels.

Figure 2 gives an overview of the multiple layers of abstraction in the cooperating robot systems. Each column represents one type of robot. The behavior level (blue) represents the highest level of abstraction for all robots. This can be *skills* or complex *behaviors*. The robot specific software (green) and hardware component interfaces (red) are unified with the BonSAI Sensor Actuator Abstraction Layer (yellow). Even skills from the small AMiRo can be seamlessly

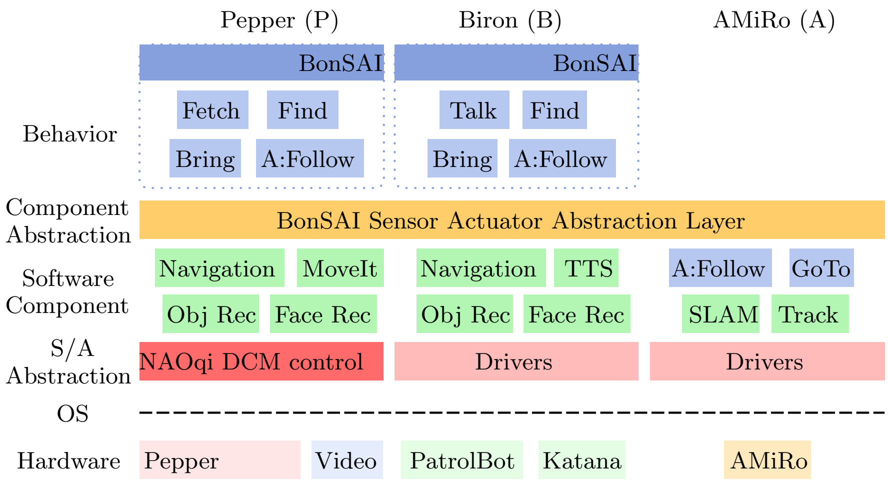


Fig. 2. System architecture of ToBI's service robots. For Pepper software components are partially deployed on an external computing resource. AMiRo acts as an external sensor/actor for the other robots. The architecture abstracts from communication protocolls which are encapsulated by the BonSAI Sensor/Actuator Abstraction Layer.

integrated into the behavior of the service robots. Thus, software components can be easily exchanged without changing any behaviors. The BonSAI layer also abstracts from the middleware and component models used on the robot which is handled on the component layer. As a consequence, a navigation skill may be defined using an appropriate ROS processing stack, while speech recognition may be defined in a different ecosystem. This approach easily extends to the processing framework of Pepper which is integrated via a ROS-NAOqi bridge.

The explicit definition of skills in BonSAI also allows to reason about them and track their success during the performance of the robot. Based on this, new elements have been introduced last year, like reporting on success and failure of tasks assigned to the robot in GSPR. A further focus has been on the multi-robot cooperation with the AMiRo platforms.

3.1 Development, Testing, and Deployment Toolchain

The software dependencies – from operating system dependencies to inter-component relations – are completely modeled in the description of a *system distribution* which consists of a collection of so called *recipes* [6]. In order to foster reproducibility/traceability and potential software (component) re-use of the ToBI system, we provide a full specification of the 2016 system in our online catalog platform [2]. The catalog provides detailed information about the soft- and hardware system including all utilized software components, as well as the facility

[2] `https://toolkit.cit-ec.uni-bielefeld.de/systems/versions/robocup-champion-2016-2016-champion`

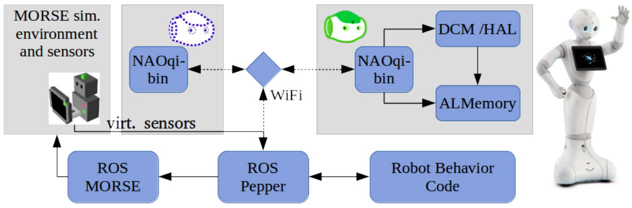


Fig. 3. For efficient testing it is essential that the architecture can be easily switched between a simulation and the real robot without changing any interface. The right box represents the physical Pepper platform while the left boxes are running a virtual robot and a separate simulation environment with MORSE.

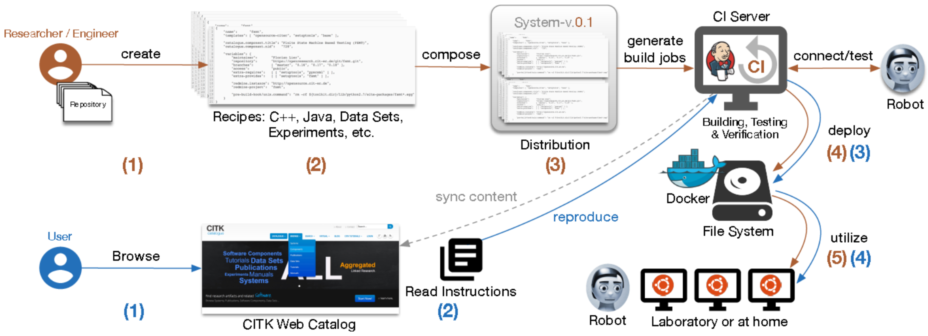


Fig. 4. Cognitive Interaction Toolkit: tool chain and workflow. The red numbers show the workflow of the system developer, while the blue numbers represent the workflow of a researcher reproducing the system.

to execute live system tests and experiments remotely [3]. The basic architecture for executing simulated or real platform test on the Pepper robot is shown in Fig. 3. Software components may be deployed on an external Wi-Fi connected computing resource or on the onboard PC of the Pepper. This is abstracted through the middleware. The MORSE simulation environment [13] allows to conduct human-robot interaction experiments and provides virtual sensors for the cameras and laser-range sensors. The virtual image streams and laser scans are published on the equivalent ROS topics which are used by the real sensors. In Lier et al. [14], we show how to utilize this framework for an automated testing of a virtual human agent interferring with the navigation path of a robot.

The development and deployment process by a researcher is illustrated in Fig. 4 (red numbers). It starts with the source code of her/his software components (Figure 4 (1)). These are often written in different programming languages and thus make use of diverse build environments. We address this issue by apply-

[3] In order to gain access to our remote experiment execution infrastructure please contact the authors.

ing a generator-based solution that utilizes minimalistic template-based descriptions (recipes) of the different components that belong to a system distribution (Figure 4 (2)). Distribution files (Figure 4 (3)) are interpreted by a generator that creates build jobs on a continuous integration (CI) server. Additionally, a special build job is created that, if triggered, orchestrates the complete build and deployment process of the system. After all jobs are finished, the system is deployed (Figure 4 (4)) in the file system and is ready to use (Figure 4 (5)). Since setting up a CI server and the required plugins takes time and requires expert knowledge, we provide prepackaged installations for CITK users. Moreover, we recently introduced deployment of CITK-based systems using Linux containers, like Docker. System descriptions and their meta data, e.g., source code locations, wiki pages, issue tracker, current build status, experiment descriptions, and so forth are frequently synchronized to a web-based catalog that also implements the CITK data model – providing a global human readable and searchable platform which is a prerequisite for open research.

4 Conclusion

We have described the main features of the architecture and technical solution of the ToBI systems for the RoboCup@Home Open Platform League (OPL) as well as Social Platform League (SSPL) 2017. BonSAI – in combination with the Cognitive Interaction Toolkit (CITK)– represents a flexible rapid prototyping environment, providing capabilities of robotic systems by defining a set of essential skills for such systems. The underlying middleware allows to extend it even to a distributed sensor network, here, defined by two service robots and an external computing resource. We further show the implementation of the overall framework as a reproducible system distribution for different robot platforms, like the GuiaBot or Pepper. The RoboCup@HOME competitions in 2009 to 2016 served for as a continuous benchmark of the newly adapted platform and software framework. In 2016, the ToBI robots gave the most stable performance throughout the competition and introduced new elements like reporting on success and failure of tasks and multi-robot cooperation. Key elements are the re-usable behavior definitions across platforms and a development approach that aims at reproducible robotic experiments and testing in simulation. This line of research will be continued in 2017 for OSPL as well as SSPL.

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5 Team information

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Description of hardware:
- GuiaBot by Adept/Mobilerobots (cf. section 2)
- Pepper by Softbank Robotics (cf. section 2)
- external computing resource (Laptop) connected by WiFi

Description of software:
Most of our software and configurations is open-source and can found at the *Central Lab Facilities GitHub* [4]

Operating System	Ubuntu 16.04 LTS
Middleware	ROS Kinetic; RSB 0.16 [8]
SLAM	ROS Gmapping
Navigation	ROS planning pipeline
Object Recogntition	Classificiation Fusion (CLAFU) [16]
People Detection	strands perception people [5]
Behavior Control	BonSAI with SCXML
Attention	Hierachical Robot-Independent Gaze Arbitration [6]
Speech Synthesis	Mary TTS
Speech Recogntition	PocketSphinx with context dependent ASR

[4] https://github.com/CentralLabFacilities
[5] https://github.com/strands-project/strands_perception_people
[6] https://github.com/CentralLabFacilities/simple_robot_gaze