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Intuitive Multimodal Interaction for Domestic Service Robots

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Abstract

Domestic service tasks require three main skills from autonomous robots: robust navigation in indoor environments, flexible object manipulation, and intuitive communication with the users. In this paper, we present the communication skills of our anthropomorphic service and communication robots Dynamaid and Robotinho. Both robots are equipped with an intuitive multimodal communication system, including speech synthesis and recognition, gestures and facial expressions. We evaluate our systems in the RoboCup@Home league, where our team NimbRo@Home won the innovation award for innovative robot body design, empathic behaviors, and robot-robot cooperation in 2009.

1 Introduction

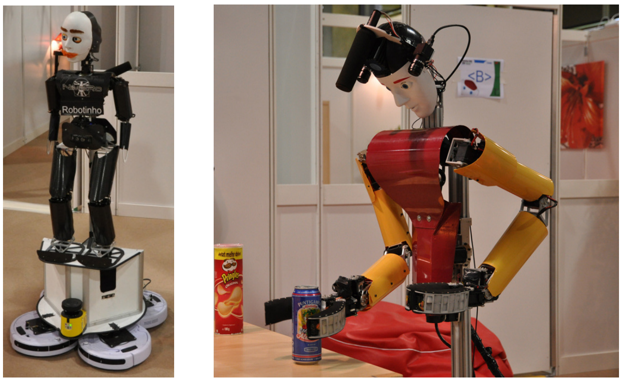

Figure 1: Our humanoid communication robot Robotinho (left) and our domestic service robot Dynamaid (right) during the RoboCup@Home competitions in Graz, 2009.

In order to leave industrial mass production and help with household chores, robots must fulfill a new set of requirements. While industrial production requires strength, precision, speed, and endurance, domestic service tasks require robust navigation in indoor environments, flexible object manipulation, and intuitive communication with the users.

Most research groups focus on mobility and manipulation. This leads to a lack of communication skills in many of the advanced service robot prototypes, like PR2 [26] or Justin [9].

Advanced domestic service robots should make use of multiple modalities such as speech, facial expressions, gestures, body language, etc. to interact with people. If successful, this approach yields a user interface that leverages the evolution of human communication and that is intuitive to naive users, as they have practiced it since early childhood.

In this paper, we present our robots Robotinho and Dynamaid. Robotinho is a full-body humanoid robot that has been equipped with an expressive communication head and an omnidirectional drive. Dynamaid has an anthropomorphic upper body, a movable trunk, and is able to drive omnidirectionally as well.

Both robots are equipped with a multimodal dialog system. They can perceive persons in their environment, recognize and synthesize speech. To express its emotional state, Robotinho generates facial expressions and adapts the speech synthesis. Depending on the visual input, it shifts its attention between different persons. Our robots perform human-like arm gestures during the conversation and also use pointing gestures generated with eyes, head, and arms to direct the attention of their interaction partners towards objects in their environment.

We developed software for solving the tasks of the RoboCup@Home competitions. These competitions require fully autonomous robots to perform useful tasks in a home environment in close interaction with the human users.

As team NimbRo@Home, our robots participated with great success at the RoboCup German Open, which took place at Hannover Messe in April 2009. Overall, they reached the second place. We evaluated our system also at RoboCup 2009, which took place in July in Graz. In this competition, our robots won the innovation award.

After reviewing some of the related work in the next section, we describe the design of our robots in Section 3. We cover the basic behavior control modules necessary for autonomous operation in Section 4. Section 5 deals with the perception of the communication partners using laser scanners, cameras, and microphones. In Section 6, we cover the details of the intuitive multimodal human-robot interaction using speech, gestures, etc. We report the experiences made during the RoboCup competitions in Section 7.

2 Related Work

Over the past century, robots became familiar figures in movies and TV series. The popularity of such robots indicates that people are receptive to the idea that these machines will one day become part of our everyday life.

Kismet [5] is a robot head containing multiple cameras which has been developed for studying human-robot social interaction. It does not recognize the words spoken, but it analyzes low-level speech patterns to infer the affective intent of the human. Kismet displays its emotional state through various facial expressions, vocalizations, and movements. It can make eye contact and can direct its attention to salient objects. A more complex communication robot is Leonardo, developed by Breazeal *et al.* [6]. It has 65 degrees of freedom to animate the eyes, facial expressions, the ears, and to move its head and arms. Leonardo and Kismet are mounted on a static platform. Mobile robots used for communication include PaPeRo [20], Qrio [2], and Maggie [11]. These robots are not suitable for domestic service tasks, though.

An increasing number of research groups worldwide are working on complex robots for domestic service applications. For example, the Personal Robot One (PR1) [27] has been developed at Stanford University. The successor PR2 is currently developed by Willow Garage.

The U.S. company Anybots [1] developed the robot Monty (170cm, 72kg), which has one fully articulated hand (driven by 18 motors) and one gripper, and balances on two wheels. The robot is supplied externally with compressed air. A Video is available online, where the robot manipulates household objects by using teleoperation.

At Waseda University in Japan, the robot Twendy-One [23] is being developed. Twendy-One is 147cm high and has a weight of 111kg. It moves on an omnidirectional wheeled base and has two anthropomorphic arms with four-fingered hands. The head contains cameras, but is not expressive. Several videos captured in the lab are available, where the robot manipulates various objects, presumably teleoperated.

One impressive piece of engineering is the robot Rollin' Justin [16], developed at DLR, Germany. Justin is equipped with larger-than human compliantly controlled light weight arms and two four finger hands. The upper body is supported by a four-wheeled mobile platform with individually steerable wheels, similar to our design. While Justin is able to perform impressive demonstrations, e.g. at CeBit 2009, the robot does not yet seem to be capable of autonomous operation in a home environment, as required for RoboCup@Home. The DLR arms have also been used in the DESIRE project [18].

The domestic service robots mentioned are designed for mobility and manipulation, but they lack significant communication skills. While they interact with common household objects, their developers did not consider intuitive multimodal communication with human users.

Closest to our research are the robots Care-O-Bot and Armar. Care-O-Bot 3 [17] is the latest version of the domestic service robots developed at Fraunhofer IPA. The robot is equipped with four individually steerable wheels, a 7 DOF industrial manipulator from Schunk, and a tray for interaction with persons. Objects are not directly passed from the robot to persons, but placed on the tray. The robot does not have a face. Armar [21] is developed in Karlsruhe. It is designed to perform some tasks in the kitchen. Armar accepts speech commands from a human wearing a head set. The robot's face cannot express any emotions.

When designing robots for human-robot interaction, one must consider the uncanny valley effect, described by Mori [15]. Humans are no longer attracted to robots, if they appear too human-like. Photo-realistic android and gynoid robots, such as Repliee Q2 [14], are at first sight undistinguishable from real humans, but the illusion breaks down as soon as the robots start moving. For this reason, our robots do not have a photo-realistic human-like appearance, but we emphasize the facial features of their heads using distinct colors.

3 Robot Design

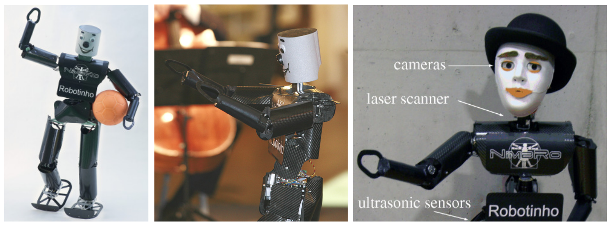

Figure 2: Our robot Robotinho was initially used as soccer player in the RoboCup Humanoid League. It conducted The 12 Cellists of the Berlin Philharmonic in September, 2006. The right image shows the communication head as well as the position of the cameras and distance sensors.

The hardware design for our robots Robotinho and Dynamaid focused on low weight, sleek appearance, and dexterity (see **Figure 1**). These are important features for a robot that interacts with people in daily life environments. In particular, the low weight has safety advantages, because the robot requires only limited actuator power and thus is inherently safer than a heavy-weight robot. The total weight of each robot is only about 20kg, an order of magnitude lower than other domestic service robots.

The low weight is possible, because we use light-weight Dynamixel actuators for the robot joints. Furthermore, the robots are made from lightweight materials, such as aluminum, carbon composite materials, and plastics. The robots are fully autonomous. They are powered by high-current Lithium-polymer rechargeable batteries and have their computing power on-board. Both robots have an anthropomorphic appearance, which supports human-like multimodal communication.

For navigation and people tracking both robots are equipped with two laser range finders (LRF), a SICK S300 on the base and a Hokuyo URG-04LX at the upper body.

3.1 Robotinho

Robotinho, shown in **Figure 2**, has been originally designed for playing soccer in the RoboCup Humanoid League TeenSize class. Robotinho is 110cm tall and has a

total weight of about 6kg. Its body has 25 degrees of freedom (DOF): six per leg, four per arm, three in the trunk, and two in the neck.
For the use as communication robot, we equipped Robotinho with an expressive 15DOF head, visible in the right part of Figure 2. To generate facial expressions it has actuated eyebrows and eyelids, mouth, and jaw. The eyes are movable USB cameras.
For the @Home competitions, we placed Robotinho on a wheeled base with four individually steerable axes. This base uses four Roomba 530 differential drives. Each Roomba is attached to the base by a Dynamixel, which measures the heading.

3.2 Dynamaid

Dynamaid's upper body consists of two anthropomorphic arms, a movable head, and an actuated trunk. Each arm has seven joints. We designed the arm size, joint configuration, and range of motion to resemble human reaching capabilities. Each arm's maximum payload is 1kg.
The trunk contains two actuators. One trunk actuator can lift the entire upper body by 1m, such that the trunk LRF measures heights starting from 4 cm above the ground. In the highest position, Dynamaid is about 180cm tall. The second actuator allows to twist the upper body by $\pm 90°$. This extends the working space of the arms and allows it to face persons with its upper body without moving the base.
The head of Dynamaid consists of a white human face mask, a directional microphone, a time-of-flight camera, and a stereo camera on a pan-tilt neck.
Dynamaid's mobile base also consists of four individually steerable differential drives, which are attached to corners of an rectangular chassis with size 60×42cm.

4 Basic Behavior Control

Domestic service tasks require highly complex coordination of actuation and sensing. To enable an autonomous robot to solve such a task, a structured approach to behavior design is mandatory.
The autonomous behavior of our robots is generated in a modular multi-threaded control architecture [22]. We employ the inter process communication infrastructure of the Player/Stage project [10].

4.1 Kinematic Control

High mobility is an important property of a domestic service robot. It must be able to maneuver close to persons and obstacles and through narrow passages. To manipulate objects in a typical domestic environment, the robot needs the ability to reach objects on a wide range of heights, in large distances, and in flexible postures to avoid obstacles. The mobile bases of our robots are very maneuverable. They can drive omnidirectionally at arbitrary combinations of linear and rotational velocities within their speed limits. The anthropomorphic arms of our robots are controlled with inverse kinematics. Robotinho uses its 4 DOF arms mainly to make gestures. The 7 DOF arms of Dynamaid can reach objects in a wide range of heights at diverse arm postures. We resolve the redundant DOF using null-space optimization [7].

4.2 Navigation

Most domestic service tasks are not carried out at one specific location, but require the robot to safely navigate in its environment. For this purpose, it must be able to drive safely along the path despite dynamic obstacles.
The path planning module only considers obstacles which are represented in the map. To navigate in partially dynamic environments, we implemented a module for local path planning and obstacle avoidance. It considers the recent scans of the LRF on the base and the time-of-flight camera on the head. The local path planner is based on the vector field histogram algorithm [24].
Individuals may feel uncomfortable, if a robot drives past them too close. We use the tracked positions of persons to influence the repulsive forces of obstacles in our local path planner. If possible, a path closer to static than dynamic obstacles is chosen.
If dynamic obstacles are inside the safety range of our robots or no obstacle free path to a destination can be found our robots ask for clearance. Robotinho endorses the request by generating an angry facial expression.

5 Perception of Communication Partners

5.1 Person Detection and Tracking

To interact with human users a robot requires situational awareness of the persons in its surrounding. For this purpose, our robots detect and keeps track of nearby persons. We combine both LRFs on the base and in the torso to track people. The SICK S300 LRF on the base detects legs, while the Hokuyo URG-04LX LRF detects trunks of people. Detections from the two sensors are fused with a Kalman Filter which estimates position and velocity of a person. It also considers the ego-motion of the robot. In this way, we can robustly track a person in a dynamic environment which we could demonstrate in the *Follow Me* task at the RoboCup@home competition.
Our robots keep track of multiple persons in their surrounding with a multi-hypothesis-tracker. A hypothesis is initialized from detections in the trunk laser range finder. Both types of measurements from the laser on the base and in the trunk are used to update the hypotheses. For asso-

ciating measurements to hypotheses we use the Hungarian method [13].
Not every detection from the lasers is recognized as a person. Dynamaid verifies that a track corresponds to a person by looking towards the tracks and trying to detect a face in the camera images with the Viola&Jones algorithm [25].
This procedure leads to empathic human-robot-interaction: When Dynamaid has to find and remember persons, it places herself in the environment and begins to spot people by looking around. People report to feel attended, when Dynamaid gazes at them during this process.
To detect and track people in the environment, Robotinho uses the images of its two cameras. The different viewing angles of the cameras allow to cover a wider field of view and to detect people (i.e., their face) at larger distances. Robotinho maintains a probabilistic belief about the people in its surroundings which is updated based on detected faces in the camera images and corresponding laser range measurements. Using this belief, the robot is also able to keep track of people when they are temporarily outside its field of view. The face detection and tracking system is described in detail in [4]. Person hypotheses from the multi-hypothesis-tracker are used to direct the gaze to yet undetected faces.

5.2 Person Identification

For the *Who-is-Who* and the *Partybot* tests, Dynamaid must introduce itself to persons and recognize these persons later. Using the VeriLook SDK, we implemented a face enrollment and identification system. In the enrollment phase, Dynamaid approaches detected persons and asks them to look into the camera. The extracted face descriptors are stored in a repository. It also remembers where it encountered a person the last time. If Dynamaid meets a person later, it compares the new descriptor to the stored ones, in order to determine the identity of the person.

5.3 Speech Recognition

Speech is recognized using a commercial ASR system from Loquendo. This system is speaker-independent and uses a small vocabulary grammar which is changed with the dialog state. We use directional microphones mounted on the robots. The speech recognition works even in noisy environments, like trade fairs and RoboCup competitions, where commonly 60-70dBA noise level are measured.

6 Multimodal Interaction with Humans

6.1 Attentional System

Robotinho shows interest in multiple persons in its vicinity and shifts its attention between them so that they feel involved into the conversation. To determine the focus of attention of the robot, we compute an importance value for each person in the belief, which is based on the distance of the person to the robot, and on its angular position relative to the front of the robot.
The robot always focuses its attention on the person who has the highest importance, which means that it keeps eye-contact with this person. While focusing on one person, from time to time our robot also looks into the direction of other people to involve them into a conversation and to update its belief. Dynamaid also gazes at tracked people by using its pan-tilt neck.
Turning towards interaction partners is distributed over three levels [8]: the eyes, the neck, and the trunk. We use different time constants for these levels. While the eyes are allowed to move quickly, the neck moves slower, and the trunk follows with the slowest time constant. This reflects the different masses of the moved parts. When a saccade is made, the eyes point first towards the new target. As neck and trunk follow, the faster joints in this cascade move back towards their neutral position. A comfort measure, which incorporates the avoidance of joint limits, is used to distribute the twist angle over the three levels.

6.2 Multimodal Dialog System

The dialog system covers a restricted domain only, which is specific for the task the robots need to perform. It is realized using a finite-state automaton. As the perception of the environment is uncertain and human users may not always react, some of the transitions are triggered by timeouts. The confidence reported by the speech recognition system is utilized to ask for confirmation in ambigous cases.
In the RoboCup competitions, Robotinho is able to give tours through the apartment. It can generate some small talk and is also able to explain itself. For the use as a tour guide, we implemented a static scenario, where Robotinho explains some of our other robots, and also a dynamic scenario where Robotinho guides visitors through the university building.

6.3 Arm and Head Gestures

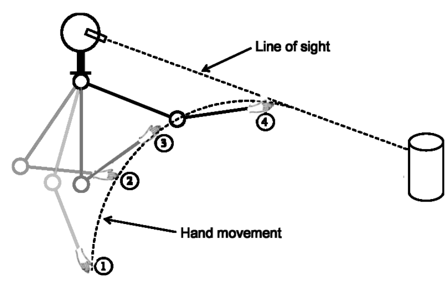

Figure 3: Sketch of pointing motion.

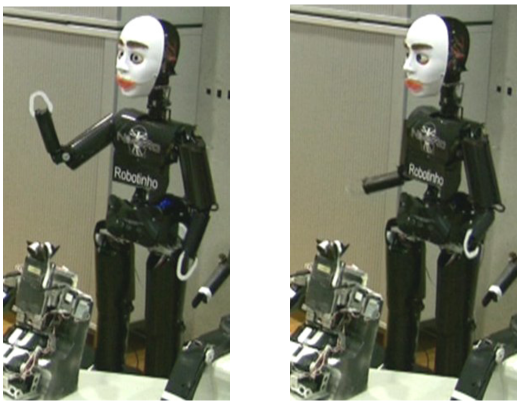

Figure 4: While interacting with people, Robotinho performs several natural gestures.

Our robots perform several natural, human-like gestures (see **Figures 4** and 2). These gestures either support its speech or correspond to unconscious arm movements which we humans also perform. The gestures are generated online. Arm gestures consist of a preparation phase where the arm moves slowly to a starting position, the hold phase that carries the linguistic meaning, and a retraction phase where the hand moves back to a resting position. The gestures are synchronized with the speech synthesis module.
• *Symbolic Gestures:* The symbolic gestures in our dialog system include a single-handed greeting gesture that is used while saying hello to newly detected people. Robotinho also performs a come-closer gesture with both arms when detected persons are farther away than the normal conversation distance. It also accompanies certain questions with an inquiring gesture where it moves both elbows outwards to the back. In appropriate situations, it performs a disappointment gesture by moving, during the stroke, both hands quickly down. To confirm or to disagree, it also nods or shakes its head, respectively. If Robotinho is going to navigate and the path is blocked a both-handed make-room gesture can be performed.
• *Batonic Gestures:* Humans continuously gesticulate to emphasize their utterances while talking to each other. Robotinho also makes small emphasizing gestures with both arms when it is generating longer sentences.
• *Pointing Gestures:* To draw the attention of communication partners towards objects of interest, both robots perform pointing gestures. As sketched in **Figure 3**, they approach with their hand the line from the robot head to the referenced object. When Robotinho wants to draw attention to an object, it simultaneously moves the head and the eyes in the corresponding direction and points in the direction with the respective arm while uttering the object name.
• *Non-Gestural Movements:* Robotinho also performs small movements with its arms to appear livelier. We also implemented a regular breathing motion and pseudo-random eye blinks.

6.4 Emotional Expression

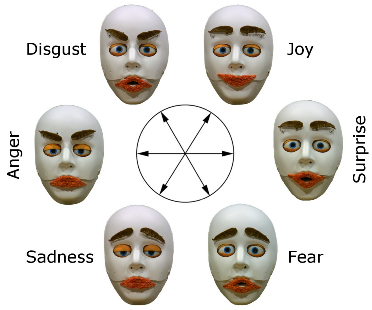

Figure 5: Facial expressions generated by expressive robot head.

Showing emotions plays an important role in inter-human communication. During an interaction, the perception of the mood of the conversational partner helps to interpret his/her behavior and to infer intention.
• *Facial Expressions:* To communicate the robot's mood, we use a face with animated mouth and eyebrows to display facial expressions. The robot's mood is computed in a two-dimensional space, using six basic emotional expressions (joy, surprise, fear, sadness, anger, and disgust). Here, we follow the notion of the Emotion Disc developed by Ruttkay *et al.* [19]. This technique allows continuous changes of the facial expression. **Figure 5** shows how we implemented the six basic expressions for Robotinho using eyebrows, eyelids, mouth corners, and the jaw.
• *Emotional Speech Synthesis:* In combination with facial expressions, we use emotional speech to express the robot's mood. Loquendo TTS supports expressive cues to speak with natural and colorful intonation. It also supports modulation of pitch and speed, and special sounds like laughing and coughing. Qualitatively, the synthesized speech is very human-like. For Robotinho we set the parameters average pitch, speed, and volume and thereby communicate the robot's emotional state.

6.5 Attention during Navigation

While guiding from one place to another, Robotinho keeps its communication partners attended. Our robot looks alternating into the driving direction and to its followers. Looking into the driving direction indicates that it notices obstacles in its driving direction. Looking into the direction of the guided people is both necessary to update the robot's knowledge about their whereabouts and to show interest in the people it interacts with. If the positions of people are known, Robotinho gives its attention to a random person. Otherwise, it looks over its shoulder to find its followers.
If Robotinho is uncertain about the whereabouts of its followers, or if they fall back, its head and upper body are turned and a come-closer gesture backed by a verbal request to follow it is performed. Additionally, it can turn its

base to look and wait for the people. If this is successful, our robot indicates that it became aware of their presence and continues the navigation.
Dynamaid also gazes into the driving direction and additionally at objects prior to grasping.

6.6 Object Handover

Figure 6: Dynamaid hands a cereals box to a human user during the Supermarket test at RoboCup 2009. Dynamaid's object handover is intuitive: On pull, Dynamaid complies to the motion of the user. If the user pulls far enough, Dynamaid releases the object.

When Dynamaid hands-over an object to a human, the user can trigger the release of the object either by a speech command or by simply taking the object. As the arm actuators are back-drivable and support moderate compliance, the user can easily displace them by pulling the object. The actuators measure this displacement. The arm complies to the motion of the user. When the pulling persists, Dynamaid opens its gripper and releases the object. **Figure 6** shows how Dynamaid hands an object to a human user during RoboCup 2009.

7 System Evaluation

Benchmarking robotic systems is difficult. While videos of robot performances captured in ones own lab are frequently impressive; in recent years, robot competitions, such as the DARPA Grand and Urban Challenges and RoboCup, play an important role in assessing the performance of robot systems.
At such a competition, the robot has to perform tasks defined by the rules of the competition, in a given environment at a predetermined time. The simultaneous presence of multiple teams allows for a direct comparison of the robot systems by measuring objective performance criteria, and also by subjective judgment of the scientific and technical merit by a jury.
The international RoboCup competitions, best known for robot soccer, also include now the @Home league for domestic service robots. The rules of the league require fully autonomous robots to robustly navigate in a home environment, to interact with human users using speech and gestures, and to manipulate objects that are placed on the floor, in shelves, or on tables. The robots can show their capabilities in several predefined tests, such as following a person, fetching an object, or recognizing persons. In addition, there are open challenges and the final demonstration, where the teams can highlight the capabilities of their robots in self-defined tasks.

7.1 RoboCup German Open 2009

Our team NimbRo [3] participated for the first time in the @Home league at RoboCup German Open 2009 during Hannover Fair.
In Stage I, we used our communication robot Robotinho for the *Introduce* task. In this test, the robot has to introduce itself and the team to the audience. It may interact with humans to demonstrate its human-robot-interaction skills. The team leaders of the other teams judge the performance of the robot on criteria like quality of human-robot-interaction, appearance, and robustness of mobility. Robotinho explained itself and Dynamaid and interacted with a human in a natural way. The jury awarded Robotinho the highest score of all robots in this test.
For the *Follow Me* test, we used Dynamaid. It was able to quickly follow an unknown human through the arena, outside into an unknown, dynamic, and cluttered environment, and back into the arena again. It also could be controlled by voice commands to stop, to move in some directions, and to start following the unknown person. Performance criteria in this test are human-robot-interaction, safe navigation, and robust person following. Dynamaid achieved the highest score at this competition.
Dynamaid also accomplished the *Fetch & Carry* task very well. For this test, a human user asks Dynamaid to fetch an object from one out of five locations. The user is allowed to give a hint for the location through speech. Dynamaid delivered reliably the requested object and scored the highest score again for its human-robot-interaction and manipulation skills.
In Stage II, Dynamaid did the *Walk & Talk* task perfectly. A human showed it five places in the apartment that it could visit afterwards as requested by spoken commands. Shortly before the run, the apartment is modified to test the ability of the robots to navigate in unknown environments.
In the *Demo Challenge*, Dynamaid demonstrated its skills as a waitress: Multiple users could order different drinks that it fetched quickly and reliably from various places in the apartment.
In the final, Robotinho gave a tour through the apartment while Dynamaid fetched a drink for a guest. The score in the final is composed of the previous performance of the team in Stage I and Stage II and an evaluation score by independent researchers that judge scientific contribution, originality, usability, presentation, multi-modality, diffi-

culty, success, and relevance. A video of the robots' performance is available at our web page[1]. Overall, the NimbRo@Home team reached the second place, only a few points behind b-it-bots [12].

7.2 RoboCup 2009

Figure 7: Arena of the 2009 RoboCup@Home competition in Graz.

Some of Dynamaid's features, such as object recognition, face recognition, the second arm, and the movable trunk became operational for the RoboCup 2009 competition, which took place in July in Graz, Austria. **Figure 7** shows both of our Robots in the arena, which consisted of a living room, a kitchen, a bedroom, a bathroom, and an entrance corridor. 18 teams from 9 countries participated in this competition.

In the *Introduce* test, Robotinho explained itself and Dynamaid, while Dynamaid cleaned-up an object from the table. Together, our robots reached the highest score in this test.

Dynamaid successfully performed the *Follow Me* and the *Who-is-Who* test. In *Who-is-Who* the robot must detect three persons, approach them, ask for their names, remember their faces, and recognize them again when they leave the apartment. Dynamaid detected one person and recognized this person among the three persons leaving. It reached the second highest score in this test. Both robots reached the second highest score in the *Open Challenge*, where Robotinho gave a home tour to a guest while Dynamaid delivered a drink.

In Stage II, Dynamaid performed the *Walk & Talk* test very well. In the *Supermarket* test, the robot must fetch three objects from a shelf on spoken command of a user. The robot must first explain its operation to the user. Dynamaid recognized all requested objects, fetched two of them from different levels, and handed them to the user. This yielded the highest score in the test.

Dynamaid also performed the *Partybot* test very well. It detected a person, asked for the person's name, went to the fridge, recognized the person when it ordered a drink, and delivered the drink.

Both robots were used in the *Demo Challenge*. The theme of the challenge was 'in the bar'. Robotinho offered snacks to the guests, while Dynamaid detected persons, approached them, offered drinks, took the orders, fetched the drinks from the kitchen table, and delivered them to the guest. The jury awarded 90% of the reachable points for this performance.

After Stage II, our team had the second most points, almost on par with the leading team. In the final, Dynamaid detected persons and delivered drinks to them. Overall, our team reached the third place in the @Home competition. We won also the innovation award for "Innovative robot body design, empathic behaviors, and robot-robot cooperation".

7.3 Museum Tour Guide Scenario

We evaluated our communication robot Robotinho in a museum tour guide scenario. It explained itself and guided visitors to two of our robots in the foyer of our institute. The audience mainly were students and employees of the university, but also visitors not associated with the university. In general, the overall appearance and the interaction using gestures and facial expressions were very well received and attracted visitors to join the offered tours. Due to the clearly arranged area and short navigation distances we chose short timeouts and distances to consider visitors as fallen back. After the tours, people reported us that they didn't expected the robot to be aware of people and were surprised of that. This reinforced our opinion that reacting on people in the vicinity of the robot during navigation is an important skill.

Recently, Robotinho was employed as a tour guide in the *Deutsches Museum Bonn*. Discussions with visitors that attended the tour evinced that people feel attended during conversations with the robot. The unintentional actions like arm movements and blinking were also positively noticed by many visitors. A more detailed quantitative and qualitative evaluation will be published elsewhere.

8 Conclusion

In this paper, we presented two anthropomorphic robots, Robotinho and Dynamaid, which were used for domestic service tasks. The robots use multiple modalities to interact with their users in an intuitive, natural way. These include speech, emotional expressions, eye-gaze, and a set of human-like, symbolic as well as unconscious arm and head gestures.

Our robots performed the tasks of the 2009 RoboCup-@Home competitions in Hannover and Graz very well. In addition to robust navigation and object manipulation, they also excelled in human-robot interaction. Their communication skills were well received by the high-profile juries.

In the future, we plan to equip Dynamaid with an expressive head as well. Then we will be able to transfer even more of Robotinho's communicative behaviors to this new platform.

[1] http://www.NimbRo.net/@Home

Instead of improving mobility and manipulation only, we are convinced that intuitive multimodal communication between service robots and their human users will be key to the success in this application domain.

Acknowledgment

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