RoboCup@Work League Winners 2012

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Abstract. One of today's overall efforts in mobile industrial robotics is the enhancement of autonomy and flexibility considering required safety issues. The new league RoboCup@Work being carried out for the first time in Mexico City, Mexico 2012, focuses on boosting research activities in this field in order to create new, innovative ideas and concepts meeting industrial needs.

This paper introduces the new league. Furthermore, it presents the approaches of the winner team LUHbots, Leibniz Universität Hannover, Hanover, Germany, at each competition in detail.

1 Introduction

RoboCup@Work is a new league of the RoboCup Federation [23]. It was carried out for the first time at the RoboCup 2012 in Mexico City, Mexico. The new league is based on existing RoboCup competitions incorporating proven concepts. However, the applicability and relevance for the industry is high, because deployment of mobile robotics in industrial scenarios is targeted. Furthermore, the new league aims to foster research and development into new and not thoroughly covered areas of industrial robotics, e.g.

- perception, using multiple kinds of sensors and introducing new concepts of sensorics to the industrial environment,
- path and motion planning, adapting established methods and developing new concepts,
- object manipulation,
- planning and scheduling,
- learning, adapting to changing or unknown environments, and
- probalistic modeling.

"Examples for the work-related scenarios targeted by RoboCup@Work include

- loading and/or unloading of containers with/of objects with the same or different size,
- pickup or delivery of parts from/to structured storages and/or unstructured heaps,
- operation of machines, including pressing buttons, opening/closing doors and drawers, and similar operations with underspecified or unknown kinematics,

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- flexible planning and dynamic scheduling of production processes involving multiple agents (humans, robots, and machines),
- cooperative assembly of non-trivial objects, with other robots and/or humans,
- cooperative collection of objects over spatially widely distributed areas, and
- cooperative transportation of objects (robots with robots, robots with humans)." [18]

Thus far, a RoboCup@Work competition consists of three parts: Two stages and the finals. Each stage contains multiple tests with varying difficulty. The first stage focuses on basic skills like perception, navigation and manipulation, the second stage consists of more complex tests merging the skills of the first stage and combining them with new elements. The finals consist of one or multiple tests of the previous two stages. Each test is subdivided into single tasks. For each fulfilled task the teams can score a set number of points. These points can forfeit due to collisions or other unwanted behaviors. In addition to the tests, teams can score points within the *Open Challenge*, analogous to RoboCup@Home. The Open Challenge is a free demonstration which is meant to be a playground for innovative ideas and solutions that do not fit into the standard tests. Although the structure of a RoboCup@Work competition is fixed, the contents of the tests varies between competitions.

The mobile edutainment robot KUKA youBot [19] was the basic platform for the teams this time. Any other robot platform meeting the prescribed requirements regarding size and functionality, e.g. having at least one manipulator equipped with a gripper, may be used as well. Since RoboCup@Work is industry orientated, the robots used for the competitions should meet professional quality standards regarding robustness and fashioning. However, a certification for industrial use is not required.

Four teams participated in the first RoboCup@Work 2012 in Mexico City. Our team, the LUHbots, has been founded in 2012 consisting of overall seven diploma, bachelor and master students from the Faculty of Mechanical Engineering at the Leibniz Universität Hannover (Hanover, Germany). The team is promoted by the Institute of Mechatronic Systems, Hanover, Germany.

The remainder of this paper is structured as follows. Section 2 briefly describes the robot platform and the team's modifications of the stock model. Section 3 introduces the tests performed at RoboCup 2012 in detail and our solutions to the posed problems. Section 4 gives an outlook about future work and concludes this paper.

2 Hard– and Software

As mentioned before, the mobile edutainment robot youBot was the basic platform for the teams at RoboCup@Work 2012. By offering the youBot, KUKA has the intention to provide a platform for professional education and development of scalable software components in mobile robotics research [7]. The robot consists of a holonomic platform and a five degrees of freedom (5-DoF) manipulator. Both components can be used separately or connected to each other. It is also possible to use two manipulators on a single moving platform, e.g. for cooperative two arm manipulation. Due to the four Mecanum wheels, the holonomic platform has a high mobility [9]. A Mini-ITX computer with Intel® Atom™ CPU integrated in the robot's base can be used for controlling the actuators. All of them, except for the gripper, provide an EtherCAT®-interface, allowing realtime communication [12]. Initially, the robot consists of rotary encoders and current sensing in each actuator. In order to enable autonomous interaction with the environment and to solve complex tasks, e.g. part handling in unknown environment, the RoboCup@Work rules allow to midify the stock platform with additional sensors. The team's youBots holds additional sensors (see Fig. 1), as descibed in the following. At the front of the youBot a Hokuyo URG-04LX-UG01 laser range finder is attached having a dimension of only 50 mm $\times$ 50 mm $\times$ 70 mm [16]. At 10 Hz, it provides a scan range between 20 mm and 4000 mm and a scan angle of 240°. The pitch angle is 0.36°. Besides others, the laser range finder can be used for mapping, localization, navigation, and safety related applications. A camera mounted at the end effector of the manipulator allows visual servoing. The webcam LifeCam Cinema™ (Microsoft Corporation, Redmond, USA) has been chosen for this task [22]. With its cylindric shape it can be easily mounted on the robot. Providing an appropriate resolution, webcams are much cheaper in comparison to their industrial counterparts.

For RoboCup@Work all robots need to have an emergency stop system. The youBot itself is shipped without any emergency system. Hence, in order to fulfill saftey requirements, a XBee-based wireless emergency system has been developed to stop the robot remotely. In addition to that, an emergency stop button at the back of the robot can be used. Another modification affects the manipulator. Originally it's rotation area covers 169° in both direction assuming that the manipulator points forwards at 0°. For being able to load objects on the youBot's cargo area without any overhead movement the arm is mounted with a static offset of 30°. This enables the up and unloading of objects with only rotational movement along the vertical axis. Thus we are able to reach any point on the cargo area as we get a new coverage of 199° CCW and 139° CW. In conclusion, with this modifications our youBot is technically prepared to cope with the RoboCup@Work tasks.

ROS in combination with the Linux distribution Ubuntu is used as software platform by all teams of this year's RoboCup@Work. Especially ROS as main framework has significant advantages:

- a huge number (more than 3,000) of open source software packages providing various functionalities is available,
- OpenCV [8] is integrated,
- software functionality can easily be split up between team members using ROS nodes,
- developed ROS nodes can be tested independently,
- visualization (rviz) and simulation (gazebo) is already integrated,
- ROS comes with a ready-to-use navigation stack,
- multiple drivers are included such as various webcam drivers and a driver for the hokuyu laser range finder.

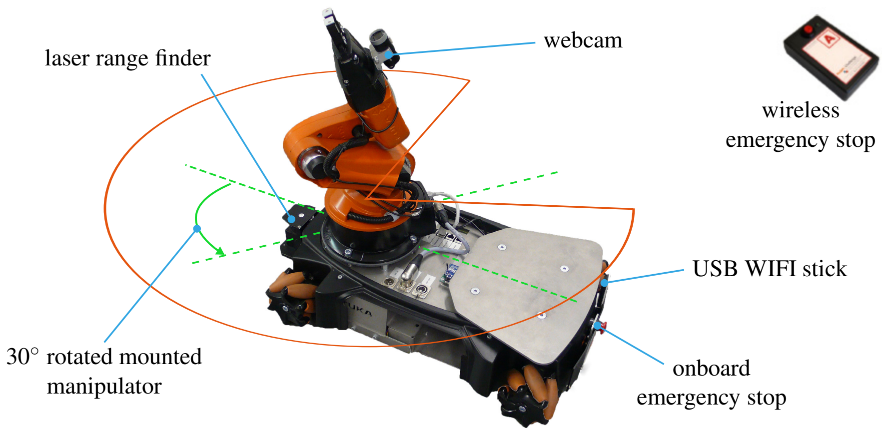

Fig. 1. Modified KUKA youBot equipped with additional sensors

3 RoboCup@Work Tests

The RoboCup@Work tests are processed in an enclosed area (arena) being confined by walls (see Fig. 2). Elevated functional areas with a height of approx. 10 cm, also known as service areas e.g. for object manipulation and pick and place assignments, are located immovably. Augmented Reality markers on the walls and floor can be used for navigation (see Fig. 2). Additional static and/or dynamic obstacles may be placed in the arena. Each challenge has to be performed within a specific, fixed time frame. Prior to the start of each test, task specifications are sent to the acting robot by means of a referee-box server. All communication with the robot has to be wireless and any intervention during a run will result in abortion.

In 2012, the first stage was composed of the *Basic Navigation Test* (BNT), the *Basic Manipulation Test* (BMT) and the *Open Challenge* (OC). Combined or competitive tests were not performed this year. Each test was conducted with only one robot in the arena at a time. In the following, the performed tests at RoboCup 2012 are described in detail.

3.1 Basic Navigation Test

Test Description. The purpose of the BNT is to prove the ability of the robot to localize itself and navigate in a known environment. With the use of a given map, it has to navigate autonomously to defined positions within the arena. The positions are tagged by floor markers (see Fig. 2). Points are received for each marker which is completely covered by the robot in a predefined position and orientation. Furthermore, extra points are assigned to the fastest team, presumed that every pose was reached successfully.

Configuration. The ROS navigation stack [21] is adopted to appropriately solve the task. Basically, it makes use of:

- a particle filter based *Adaptive Monte Carlo Localization* algorithm (amcl) [14]
- path planning algorithms with global and local planning according to the starting, current and goal pose

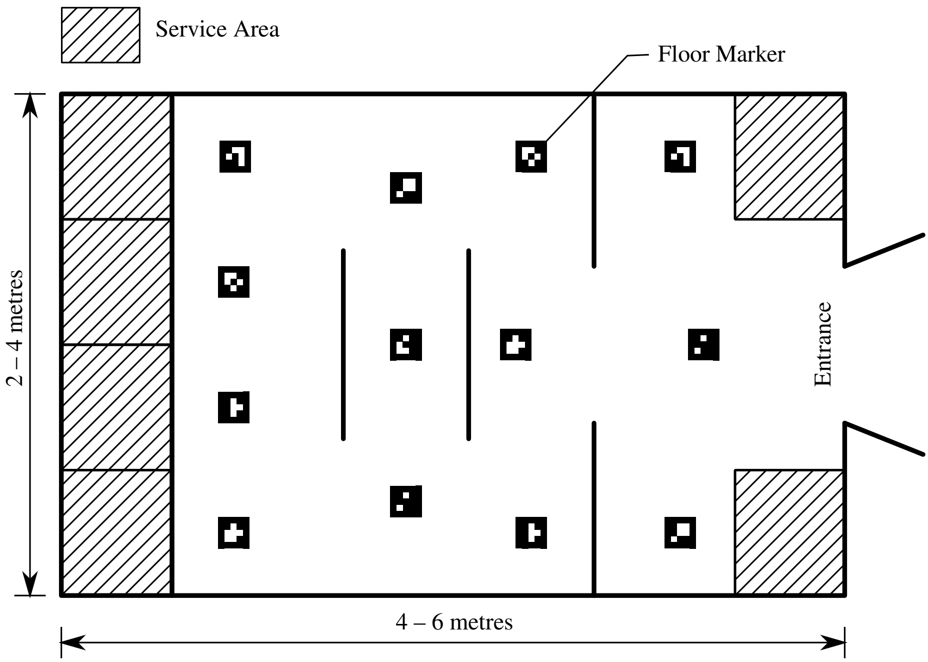

Fig. 2. RoboCup@Work arena 2012 [18]

- an environment map
- the (laser–) sensor and odometry data

The general structure of the stack is visualized in Fig. 3.

The navigation stack is configured for a holonomic robot with rectangular base frame and planar laser scanner input. Furthermore, gmapping [15] is used to create environment maps.

Limitations of the Utilized Navigation Stack. Although the youBot is a holonomic robot, the navigation stack only allows motion in directions that are sensed by the robot, i.e. in the range of the laser scanner in order to prevent collisions. Any backwards or sidewards movements are constrained. Since the floor markers have to be covered completely, the navigation to and the localization at the goal position have to be accurate. Particle spreading and imprecise base-movement result in the need of permanently readjusting the position close to the goal pose. Here, the constrained directions of motion additionally complicate the positioning. The most crucial issues are the positions of floor markers, being close to walls compared to the youBot's dimensions. For obstacle avoidance, the navigation stack inflates the outline of the walls to a certain radius (which ideally represents the longest side of the robot's base) when calculating the safely accessible area. With a radius that is sufficient to prevent collisions, the floor markers are at positions that would demand the robot to trespass the inflated area. This, on the other hand, results in random recovery behavior that handicaps successful navigation.

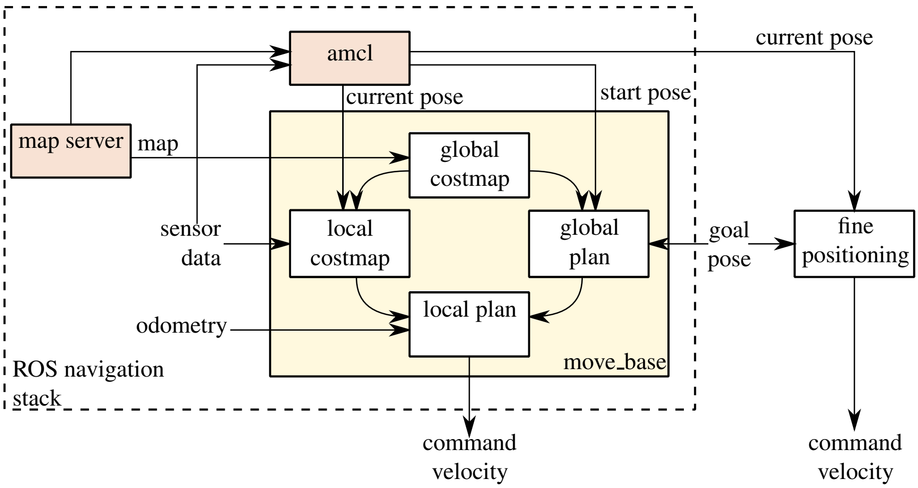

Fig. 3. Scheme of ROS navigation stack [21] and developed fine positioning mode

To sum up, the navigation stack is able to guide the robot close to the goal position. However, it is not possible to reach a desired position with the requested accuracy. In contrast, the disadvantageous goal positions combined with constrained and imprecise movement and particle spreading lead to the robots to perform uncoordinated recovery behavior at the goal positions, not managing to successfully complete the task.

Solutions. The navigation stack is used to guide the robot as close as possible to the requested pose without triggering recovery behaviors. Afterwards, the algorithm switches to an additionally implemented fine positioning mode (Fig. 3). During these time, the current pose is compared to the goal pose on basis of the latest amcl pose estimate. The difference is transformed and the resulting velocity commands are directed to the base actuators. With a constant sampling frequency, the algorithm is looped until a threshold is reached that provides sufficiently accurate positioning.

The developed fine positioning eliminates the constrained movement and reduces the particle spreading thanks to the simple and direct goal approach. The obstacle inflation is neglected because of the very limited space of motion during the fine positioning. Furthermore, no moving obstacles were placed in the arena at the basic navigation test in 2012. Thus, the risk of collisions could be eliminated. As one can see, this approach is able to overcome all the obstacles hindering a successful task completion.

With this considerably simple modification, the LUHbots were able to reach the goals quickly and accurately being the only team performing a complete test run.

3.2 Basic Manipulation Test

Test Description. The aim of the BMT is to prove the ability to recognize different objects and manipulate them. For the RoboCup@Work 2012 the object pool contained ten different objects of silver or black color, e.g. hexagon head and hex socket screws, aluminum profile rails, and screw nuts in various sizes.

In preparation for the test, five objects are nominated and placed in random configuration in a defined service area. The test starts when the product names of three of these objects are sent to the youBot by the referee-box. Those have to be grasped and transported to the neighboring service area.

The task contains three main parts: The recognition of objects, e.g. by means of a camera, manipulation and transportation of the objects with the robot. The scoring rates a robust perception and the ability to distinguish different objects individually. Furthermore, it asks for a fast and correct identification of the objects and for safe manipulation.

Configuration. Many approaches of object recognition with 2D cameras are based on feature detection and matching algorithms, such as SURF or SIFT algorithms [24][20]. Unfortunately, the objects used for the RoboCup@Work do not have enough unique features for a robust identification using these techniques.Therefore, the proposed approach takes the object geometry, i.e. its contour for identification.

For the contour extraction within an image captured using a mono–camera the following image processing pipeline is proposed: The color image is undistorted and converted into a gray scale image. In order to extract the contours, the image is first converted into gray scale and thresholded in order to obtain a binary image. Each object is stored in a database containing specific information concerning the contours, e.g. the aspect ratio. Several following filters delete undefined contours until only geometries within a defined tolerance range remain.

In the following a brief description of each step is given. Fig. 4 gives a overview about the single steps processed by the recognition pipeline. Furthermore, Fig. 5 provides an example of the presented filter stages.

Processing of a Binary Image. For the processing of a binary image three different methods are implemented: A threshold converter [4], an adaptive threshold converter [1] and the canny edge detector [2]. The canny edge detector is the most advanced approach. Nevertheless, regarding the given task, a simple threshold converter achieves the best results in terms of robustness and reliability. With the converter it is possible to separate silver from black objects because pixel that do not fit the target's color are ignored.

Contour Filtering. The distance between the wrist–fixed camera and object is constant. Thus the contour of an object does not vary and a elimination process is capable of identifying the target object. Furthermore the identification does not need to be scale invariant. Nevertheless, since the orientation of the objects is not given, the approach needs to be rotation invariant. The methods used within the proposed contour filtering are a contour size filter, an aspect ratio filter, a size filter and a shape matcher.

- **contour size filter:** To eliminate contours resulting from image interferences a tolerance field is implemented.
- **aspect ratio filter:** The algorithm calculates a minimum rotated bounding rectangle for each remaining closed contour and returns its aspect ratio.
- **size filter:** Objects of the same type and similar aspect ratio, but different size are separated by the absolute size of their bounding box.
- **shape matcher:** For a robust shape matching, this method calculates the Hu-moments [3] up to the third magnitude.

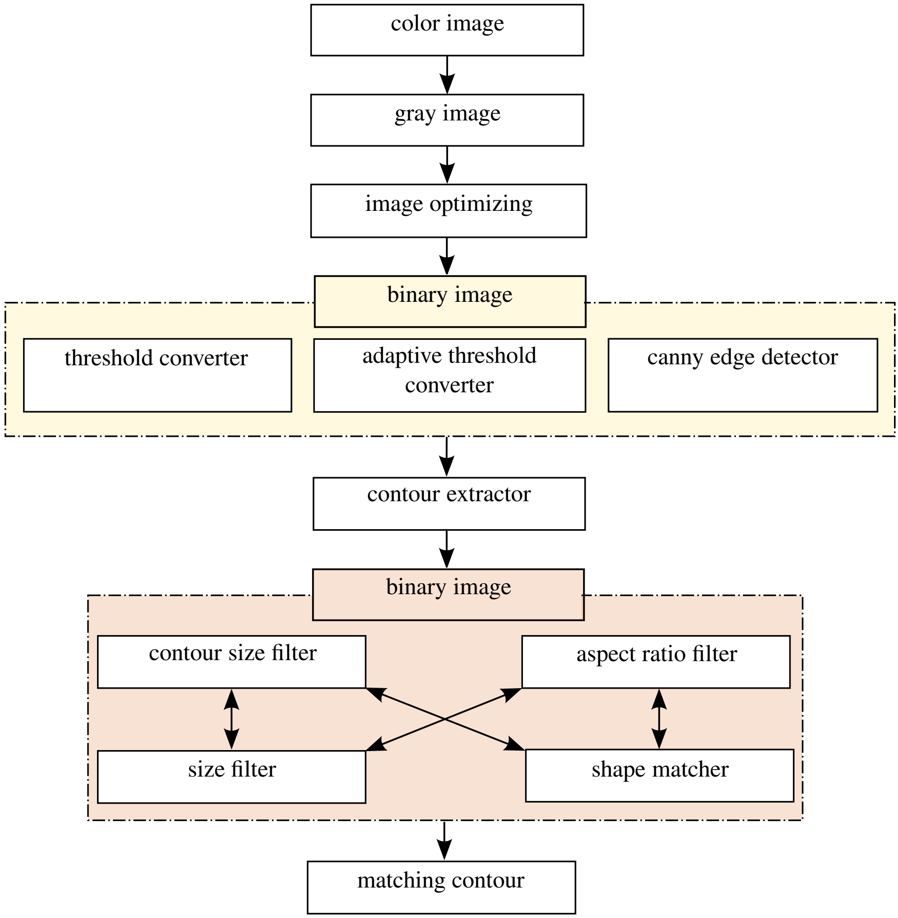

Fig. 4. Different steps of the visions class, that is capable of object recognition and identification using the geometry of an object

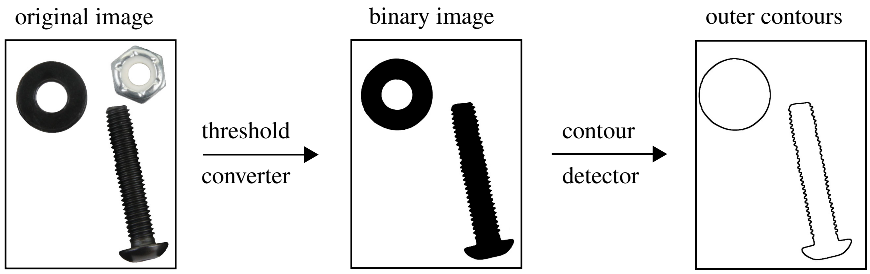

Fig. 5. Example for image processing, from original image to outer contours

Grasping. In order to grasp a detected object, it is necessary to determine its orientation. The aforementioned algorithm generates this information for the filter stages in form of a rotated bounding rectangle. Hence, only the longer side of the rectangle needs to be determined as well as its angle to the horizontal. The centre point of the box serves as the grasping point. Larger screw nuts represent an exception: The space of the gripper jaws is not sufficient to enclose such objects. Therefore, alternative grasping points need to be defined, i.e. by teaching. Since the orientation of the objects can vary the robot has to align itself according to the image before grasping.

Computational Effort. The algorithm works in a resource efficient manner. The image processing is calculated by the on-board computer and, thereby, delivers an average rate of more than 1 Hz. The different filter stages lead to a preselection of suitable objects. Sequencing the filter stages analogous to the needed computing time decreases the overall processing time.

Advanced Features. At the RoboCup@Work 2012 all objects ware placed plain on the service areas. Therefore, a top view on these objects is sufficient. For enabling the identification of arbitrary placed objects in the future, a front view has already been developed. Regarding future requirements, further derivatives of the object recognition class have already been implemented. These extended functions include the removal of image interferences on the binary image as well as the possibility to perform a more detailed image analysis not just per frame but for small sequences. A color filter that constrains a certain colour scale is already included. Furthermore, our vision class contains an implementation of the SIFT algorithm for the identification of textured objects by means of certain characteristics. All methods are modular and can be implemented in different stages of the recognition pipeline.

3.3 Open Challenge

During the Open Challenge each team has the opportunity to demonstrate its own strengths and capacities in five minutes giving a presentation simultaneously. The Open Challenge is evaluated by the following criteria [18]: "

- Relevance and applicability to industrial tasks,
- reuse for different platforms and robustness to different environments,
- professionalism of robot development and use of simulation technologies,
- novelty and scientific contribution,
- difficulty and success of demonstration."

Our presentation is divided into two parts that are described in detail in the following text: The first part presents the *ButlerBot Application* demonstrating object recognition and complex manipulation. The second part contains a human machine interaction.

ButlerBot Application. At the end of a long working day, a cool drink appears like a welcoming refreshment. Treating a robot such an ordinary task is not that simple but requires highly sophisticated image processing and manipulation capabilities. In the proposed application, the youBot retrieves a desired brand of drink and serves it autonomously. The recognition of the bottle requires a two staged solution: In the first step the area is analyzed for objects utilizing a shape detection algorithm. Afterwards, a SIFT algorithm is applied to the preselected shapes. When the correct brand is identified by its label, its position is approximated to grasp the bottle. Finally, the contents of the bottle is poured into a tumbler. This requires a coordinated motion of the manipulator. Therefore, we use a modified path planning based on fourth order polynomial velocity profiles for a smooth and jolt free motion [17]. In order to plan a desired cartesian trajectory considering collisions, endpoints and viapoints [11] are defined. In addition, the path is parameterized in terms of velocity and acceleration. Using the inverse kinematics, the cartesian points are transformed into jointspace, where the path for each joint is calculated. This ensures a safe motion along the desired trajectory with minimized computational load.

Regarding industrial applications, the demonstration shows how hazardous and/or valuable liquids can be handled autonomously by an autonomous robot. In addition, the relevance of the developed methods of image processing and path planning is reinforced.

Human Maschine Interaction. The second part of the LUHbot's Open Challenge presents an approach for a human machine interaction to control the youBot by hand gestures. Therefore, both hands are tracked using an ASUS Xtion Pro Live Camera [6]. It's structed-light 3D sensor uses the aberration of projected light patterns to measure the depth of the environment. The left hand moves the platform and the right hand the robotic manipulator. As a middleware, OpenNI [5] is used to detect the skeleton and return coordinate frames in ROS' tf [13].

After a calibration process, the positions of the current hand fixed coordinate frames are compared to their initial pose. For the base, the difference is used to calculate velocity values for the driver, according to the hand movements (Fig. 6). The youBot arm navigates to teached in positions depending on the performed gesture. A defined final gesture exits the application.

Fig. 6. Hand gesture control of the robot - two coordinate frames are placed inside the user's hand

4 Conclusion and Future Work

In this paper, the new league RoboCup@Work, carried out for the first time in Mexico City, Mexico 2012, was introduced. Furthermore, specific approaches of the RoboCup-@Work team LUHbots were presented.

For enabling new teams to take part in the RoboCup@Work league, the basic tests will remain as a part of the competition. New challenges may include more complex tasks being closer related to real-world problems and interests of the manufacturing industry. Human machine and machine machine interaction will rise in significance [10].

For fullfilling the upcoming requirements, our algorithms as well as our platform will have to get more sophisticated, e.g. the gripper will be modified for grasping objects having greater sizes. The robot is going to be equipped with further sensors for a more robust object detection on structured surfaces. Therefore we currently implement 3D-sensors for extending the perception capabilities to the third dimension. Especially in the logistics context, a huge number of different objects w.r.t. their shape, weight or color, have to be handled. The perception has to be more flexible in order to even manipulate unknown objects. Regarding the fact that in logistics a huge number of objects has to be handled, our target is to become more flexible in handling even unknown objects. An iterative, intelligent grasp algorithm can be considered for this purpose. To see the artifical intelligence in a bigger context, the robot has to be enabled to react autonomously on unpredictable incidents and learn from it. Within the extension of the motion planning functionality of the manipulator, a force and torque controlled solution besides velocity control is in progress in order to implement additional methods for collision avoidance. This extension can be used to increase the joint rigidy in a certain direction to keep the endeffector in a defined workspace. Furthermore the force control can even simplify the uncomfortable process of teaching the path points by conducting the endeffector manually to the goal poses [11].

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