Team Description Paper robOTTO
RoboCup@Work 2019

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Abstract. Team **robOTTO** is the *RoboCup@Work League* team of the Otto-von-Guericke University Magdeburg, formerly participating in the *Robocup Logistics League* since its founding in 2010. In our team, we combine the expertise from Computer Science, Electrical and Mechanical Engineering to solve @Work's unique challenges while fostering knowledge exchange between the different leagues.

Keywords: RoboCup@Work, robOTTO, RoboCup2019

1 Introduction

robOTTO was founded as a *RoboCup Logistics*[4] team in 2010 by nine students from different fields, enabling exchange of knowledge and views between the members. After achieving second place 2010 in Singapore the team continued to attend following RoboCup competitions with further successes in 2012 (4th Place) and 2013 (2nd Place). The change from *RoboCup Logistics* to *@Work League* helped to broaden the expertise of the team and in fact eased the *Crossover Challenge*[6] at the *@Work League*, resulting in a first place at world cup in Leipzig 2016. In 2012 a first attempt at a second competition resulted in an 8th place in the *2D Soccer Simulation League*. With regards to broad rule and equipment changes in the *Logistics League* in 2015 we decided to participate in the *@Work League*[3], as the Computer Science Faculty already had some experience on the **KUKA youBots**[1], thus providing a pool of experienced students and easy integration into courses and research projects. The team competed in the world cup 2015 in China and reached 6th place followed by the world cup in Leipzig in 2016, where we scored 4th. Last year was very successful for us, resulting in a third place at the GermanOpen and a second place at the world cup in Japan.

Task	Name	Field / Role
Organisation	Sanaz Mostaghim	Responsible Professor
	Sebastian Zug	TC Member
	Arndt Lüder	Liason to Mechanical Engineering
	Stephan Schmidt	
	Christoph Steup	Team Leader
	Martin Seidel	Co-Team Leader
	Franziska Labitzke	
Navigation	Alpha Mary Skaria	Computer Science
	Shruti Subramanian	Computer Science
Hardware	Nils Harder	Electrical Engineering
	Gerhard Jörges	Electrical Engineering
	Philipp Busse	Computer Science / OC Member
	Kai Rüssel	Mechatronics
	Jovel C. Jose	Computer Science
Manipulation	Rodion Marynych	Electrical Engineering
	Hauke Petersen	Mechatronics
	Anusha Mathew	Computer Science
Recognition	Johannes Kopton	Cybernetics
	Adrian Köring	Computer Vision
RobotCoordination	Lukas Hoyer	Computer Science
	Fabian Richardt	Computer Science

Table 1. Overview of **robOTTO** team members by task and field of studies or role

2 Team Structure

Currently, the team consists of 17 active members, whereas the professors are not involved in the development and only provide guidance and organizational support. Since the team is mainly composed of students, who leave the team after finishing their studies, we have a young and dynamic team of students. Depending on the new members and their backgrounds, the team can largely benefits from a diverse set of expertise. The current team members provide a large spectrum of topics from cybernetics and computer science to electrical engineering to the team as shown in Table 1. The new students provide new ideas and also new challenges to the team. Currently, the new members try to ease the use of the robot in the competition to minimize human errors, as they found the work-flow quite difficult.

3 Robot Description

The standard **KUKA youBot** does not provide any sensory equipment. Modification were necessary to use the robot in the @Work league. To minimize effort and maximize results most of the additions are COTS, used in the robotics community. Our modification relate to the sensory equipment consisting of an

additional camera and two laser scanners and to the manipulation system extended with a specialized gripper. Additionally, we switched to a more powerful PC.
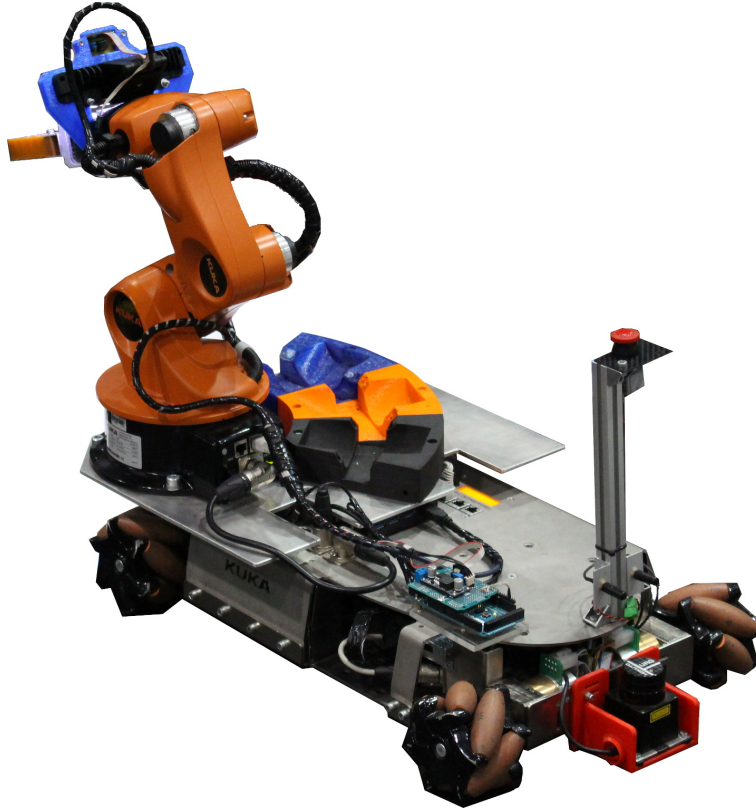

Fig. 1. Modified KUKA youBot

3.1 Changes to the standard Platform

Camera We use an **Intel RealSense** RGB-D camera which provides registered point clouds as well as an RGB-D image. Currently, we focus on the colour data for recognition and use the depth image as a highly flexible distance sensor. Around the lenses and projectors of the **RealSense** we mounted an oval-shaped ring of LEDs to improve lighting conditions and enable a reliable object detection and classification. During navigation the **RealSense** camera is used to detect *barrier tape*.

Gripper The objects of the @Work league have varying shapes and sizes. After preliminary tests we observed that the normal metal gripper on the **KUKA youBot** cannot reliably handle many of these objects. Our current gripper is based on an custom 3D-Printed mount using servos by **Dynamixel** and **Finray**-fingers by **Festo**, which are controlled by an **Arduino**. Current development focus on correctly identifying and handling error cases like the loss of an object. Additionally, we aim to improve the grasping of not perfectly aligned objects.

Computing and Connections An **Intel Core i7 NUC** was fitted into the robot as a replacement for the original Atom-based computer to enable more complex algorithms for navigation, path planning and task optimization. Additionally, an **Arduino** was fitted to the chassis to integrate various embedded components like servos, time-of-flight distance sensors and LEDs. The hardware and software architecture is modularized through defined interfaces to provide a stepping stone for students inexperienced with programming to experiment without needing the whole development stack used on the main robot.

Laser Scanner Mounting Brackets The team uses **Hokuyo URG-04LX** laser scanners. These provide appropriate distance measurements in a 240° radius with a maximum distance of 5.5 m. A reliable localization is possible if the laser scanners are exactly parallel to the ground. To this end the team designed reliable, adjustable mounting brackets, which were 3D printed by the team to prevent tilt errors even at the edge of the scanner's measurement range and shield the expensive sensors in the case of accidental collisions.

3.2 Future Modifications

Batteries and Power Supply We originally planned to replace the batteries and power-supply completely for a lithium-ion based system, but the experiences gathered while transporting batteries by plane for last years' world cup in Nagoya (Japan) put a stop to that plan as lithium batteries in the required size are not allowed to be transported on passenger planes without special permits. Our alternative solution for the mid-term will be to replace the internal charging circuit to enable full capacity charging and prevent deep discharge of one battery cell which seems to be caused by the control-panels power draw even if the robot is turned "off".

Replacement of the Upper Case For the time being, the upper case of the **youBot** is a bended steel plate, that's connected to the bottom panel. On the top there are recesses for the display, various ports (USB, LAN, power connection) and threaded holes to mount the Arm. Beneath the steel case is the electronics.

We have extended the upper case with an aluminium plate. It provides more place for an inventory and gives the opportunity to offset the arm to the side, see Figure 1.

The newly designed and manufactured upper case completely replaces the old top cover of the YouBot. It provides the option to access the underlying electronics easy, while extending the space inside the robot. This enables another **Intel Core i7 NUC**, the power supply of the grippers and our **USB3** hub to be stored inside the robot, see 3.1. Furthermore, the inventory, emergency switch and arm has pre-build mountings on the new case. Thanks to multiple mounting holes the inventory can be offset and additional parts can be added easy to the surface. However, integration and testing of the new cover is currently in progress and it remains an open question if it will be used in this years' competitions.

4   Software Architecture

In this section we want to describe the main software components and how they interact. We use the **Robot Operating System (ROS)**[5] in the *Kinetic* version running on **Ubuntu 16.04**. The main advantages are the communication abstraction and the great number of easy-to-use debug tools.

4.1   Overview

Fig. 2 shows the interaction of our software components. They are described in detail in the following sections.
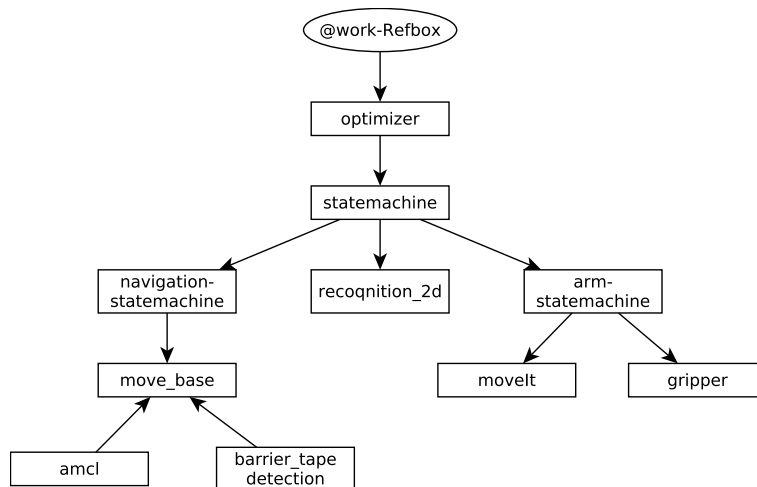

Fig. 2. Overview of the main software components of the robOTTO @Work framework.

State-Machine and Optimizer Core elements of the robot software architecture are the optimizer and the state-machine, which are responsible for coordinating the other modules of the robot like vision, navigation and arm movement.

The transportation tasks, which the robot has to fulfil, are generated by the @work referee box of the league and transferred to the robot. On the robot side the *receiver_node* is used for processing and forwarding those messages to the optimizer. The optimizer searches for a sequence of transport tasks which reaches the maximum score within the time limit. Subsequently it generates *SubTasks* as an input for the state machine. Typical *SubTasks* are picking up an object, placing an object or moving the robot to a workstation.

The state machine contains a logic for every *SubTask*. The logic determines a graph of parametrised actions which are necessary to perform the *SubTask*. Common actions are the *MoveAction*, *ArmAction* and *VisionAction*. They control the sub-state machines of the corresponding robot modules. For instance a simplified *PickLogic* consists of following actions:

1. **ArmAction** moves the arm to the pose for barrier tape recognition.
2. **MoveAction** moves the robot to a specified workstation.
3. **ArmAction** moves the arm to the pose for object recognition.
4. **DetectAction** looks for the specified object on the workstation.
5. **ArmAction** picks up the object which was localized by the vision and place it in the inventory.

Because a reliable state machine is critical for the success of a robot performance, it is one of the most intensively unit tested modules of the robot.

World Model The world cup 2017 in Leipzig showed that the complexity of the tasks and the environment is difficult to handle in our current software architecture. To incorporate additional information on the state of the arena or the robot lots of changes to code and interfaces were necessary. To mitigate this engineering issue, we decided to manage the information on the world in a central component. The resulting world model component allow us to store, track and replay changes to the robots and the arenas state. Additionally, we add support to add and modify the data in the world model of a specific task and visualize it. The major benefit of this approach is the stability of interfaces between our functional *SubTask* components, as well as the centralized point for team members to add and request information on the world. Finally, the visualization tool gives us better insights into the robots current behaviour and choices to ease debugging.

Self learning Object Recognition - recognition_2d Last year we switched from 3D point cloud recognition to a 2D image approach. Therefore, we implemented an image processing based segmentation algorithm. For classification the images are passed through a self-implemented *artificial neural net (ANN)*. The *ANN* takes the preprocessed RGB image (or perhaps depth map in the future) as its input and provides a probability value for each object as output. The training of the *ANN* uses the recorded and annotated example image streams as input and outputs the parameters of the *ANN*. The object features are learned

automatically during the training of the neural net. The orientation of the objects is determined using linear approximation. Our current goal is to improve the recognition results under poor lighting conditions and with unfavourable backgrounds.

Path Planning for Industrial Robots The navigation of industrial robots has to be developed with multiple competing influences in sight, as fast movement and collision avoidance are both critically important to successfully participate in *RoboCup@Work*. Other factors are more subtle, like predictability of behaviour and easy maintenance and adaptability. The last two points are especially important in the context of RoboCup as a competition of students, where team members and responsibilities switch regularly and members have to be able to familiarise them self with the code, often on a short notice.

The current navigation stack used by robOTTO supports two different approaches. The first approach uses the **DWA-Planner (Dynamic Window Approach)**[2] which is open source code and the standard planner for holonomic platforms in **ROS**. Since, it is quite complex with many configurable parameters we use a slightly modified parameter-set which was made available publicly by the **b-it-bots** team for usage with the **KUKA youBot**.

The second approach is a minimal implementation of a local Planner which relies on the global planner for object avoidance to keep the complexity and feature duplication down. It was developed after preliminary tests with the **DWA**-Planner showed unpredictable and often oscillating behaviour depending on a multiple factors like CPU load and floor conditions.

Integration of the MoveIt! Trajectory and Kinematics Stack The previously used kinematics stack for the manipulator used by the team, **SAMIA**, was built by former member Stefan as a by-product of his Master's Thesis and subsequently adapted for the @Work competition. But with Stefan gone we now face problems maintaining and extending the codebase. This led to the decision to abandon our own stack in favour of **MoveIt!**[1]. **MoveIt!** is an open-source motion planning framework originally developed by Willow Garage, which unifies motion planning kinematics, collision checking and dynamic three-dimensional environment representations. As it was initially developed to be used with **ROS**, it offers a high degree of integration with existing packages and tools, such as **RViz**. The stack's incorporation into our code, as well as the creation of the arm-state-machine Figure 2 and interfacing with our main state machine was done by Hauke. Since then it proved to be a viable alternative to our previous solution and had successfully been used at GermanOpen 2016 in Magdeburg and RoboCup 2016 in Leipzig. One of the stack's issues on our platform was the calculation time required to generate a valid movement trajectory. For this purpose we have developed a **ROS** package which allows caching static trajectories (e.g. when placing an object in one of the inventory slots) and integrate

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[1] http://moveit.ros.org/

them in dynamic trajectory paths to speed up the calculations. Currently, we are working on a feature allowing quick movements within a small area without time-costly kinematic calculations, an option much needed for the upcoming implementation of the Precision Placement Task.

Barrier Tape Detection The Barrier Tape Detection is asked to spatially locate barrier tape strips given a camera image and position.

To achieve this, we first detect the barrier tape in the image. This is done using a semantic segmentation on the camera image also used for object detection and recognition. However, in this case a convolutional neural network is used, which combines the task of filtering, segmentation and recognition. We used **Tensorflow** to implement the network and train it. The output of the network is an image of white pixels, where the barrier tape was detected. The training samples are generated using images of the used barrier tapes in the competition overlayed on various background images and lighted by **Blender**. To get the world coordinates of the barrier tape we cast rays from the camera through the white pixels in the mask into the scene and find intersections with the ground plane. All such intersection points finally form the resulting point cloud, which is fed to the navigation stack as an additional sensor. The only manually configured part of the *Barrier Detection* is the calibration of the mapping of the 2D camera coordinates to the 2D map coordinates of the navigation.

4.2   Future Software Components

Precision Placement SubTask To start the *PPT-SubTask* the Robot picks up the object and moves to the PPT-Table. The Vision recognizes the specified hole. Once the robot is situated in front of the right opening the arm picks up the object out of the inventory and moves directly above the hole the object needs to be placed in.

To cope with the movement errors of the arm the PPT controller moves the object slightly in all possible directions, while the visions compares object and opening and feeds back the information to the PPT controller. The controller calculates the best position, which is needed to successfully place the object in the hole. After the object is at the optimal position above the opening, the PPT controller tells the arm to lower it closer to the opening. During the lowering process the vision checks the alignment of object and opening to ensures a successful process. As soon as the object is close enough above the opening the gripper drops the object straight into the hole.

Zero-Force Training Mode for the YouBot's Arm To enable an easy Teach In process for arm configurations used in the arena, we want to develop a Zer-Force Mode for the robotic arm. To this end, we aim to provide a lookup table of arm configurations and the necessary forces for each joint. An interpolation will use these samples to automatically employ the necessary force to compensate gravity in all configurations of the arm. The lookup matrix shall be created by an

autonous learning process to allow easy adaption to changes of the constrcution or geometry of the arm itself.

5 Conclusion

With the influx of new team members and the continued participation by last years members we are cautiously optimistic that we will be able to build upon the work done last year. Expected changes to the rules of the competition mandate some overhauls of components like PPT control and the *Round-Table* grasping and detection mechanism. The last participation left us with a code base solving most of the tasks of the @work league. This enables us to focus this year on testing and improving the robustness of the working solutions, while adapting them to the new rules.

Acknowledgements

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