

Team Description Paper robOTTO

RoboCup@Work 2021

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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*[5] 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*[9] 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*[4], 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. 2017 was very successful for us, resulting in a third place at the GermanOpen and a second place at the world cup in Japan. In Montreal (Canada) the team achieved the first place in the Arbitrary Surface Challenge. In the last WorldCup in Sydney (Australia) the team achieved the Vice-World-Champion title again. In 2020 no real world cup was done and the team achieved a best-presentation award in the Virtual RoboCup Asia Pacific Open (VRCAP).

2 Team Structure

Task	Name	Field / Role
Organisation	Sanaz Mostaghim	Responsible Professor
	Arndt Lüder	Liason to Mechanical Engineering
	Stephan Schmidt	Liason to Mechanical Engineering
	Christoph Steup	Team Leader
	Martin Seidel	Co-Team Leader
Navigation	Anna Klobertanz	Electrical Engineering
	Nils Harder	Electrical Engineering / OC Member
	Niklas Harriehausen	Mechanical Engineering
Hardware	Nele Traichel	Computer Science
	Gerhard Jörges	Electrical Engineering
	Leander Bartsch	Electrical Engineering
Manipulation	Inga Brockhage	Electrical Engineering
	Hauke Petersen	Mechatronics
Recognition	Adrian Köring	Computer Vision
	Jakob Rühle	Electrical Engineering
	Anton Striecks	Medical Technology
RobotCoordination	Wiebke Outzen	Computer Science
	Fabian Richardt	Computer Science
	Jurek Rostalsky	Mathematics
	Franziska Labitzke	

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

Currently, the team consists of 16 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 benefit 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.

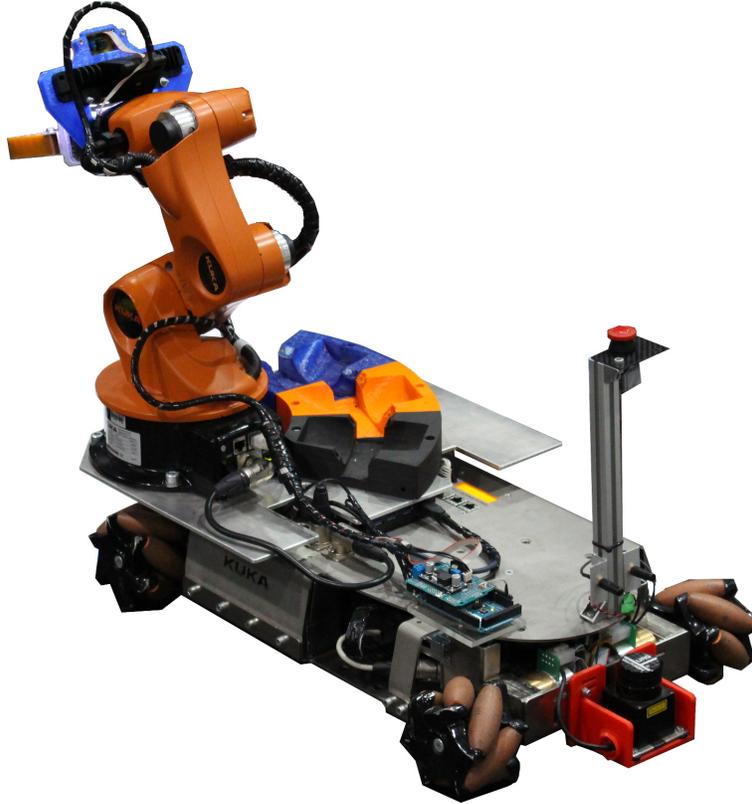


Fig. 1. Modified KUKA youBot

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 a 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.

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.

Lithium Polymer-based Battery System The original lead-based batteries of the YouBot have two major drawbacks. Firstly, they are incredibly heavy,

which increases the transportation cost when flying. Secondly, their contained energy is rather scarce compared to the power necessary for all the components. Currently our bot lasts at max 30 minutes, which is quite limited. Because of these reasons we decided to switch to Lithium-Polymer-based batteries. But instead of using single cells, we use Bosch tool batteries, which are widely available and raise no suspicion at the airport. To this end, we integrated two off-the-shelf buck-boost DC-DC converters for 12V and 24V as well as a customly designed PCB to hold voltage and current measurement as well as emergency switches to cut the different power rails. The current setup uses two batteries in parallel, which allows us to Hot-Swap the batteries without powering down and up the bot. Because of the ongoing Corona-Pandemic we could not test the endurance of the new system.

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)**[7] in the *Melodic* version running on **Ubuntu 18.04 LTS**. 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.

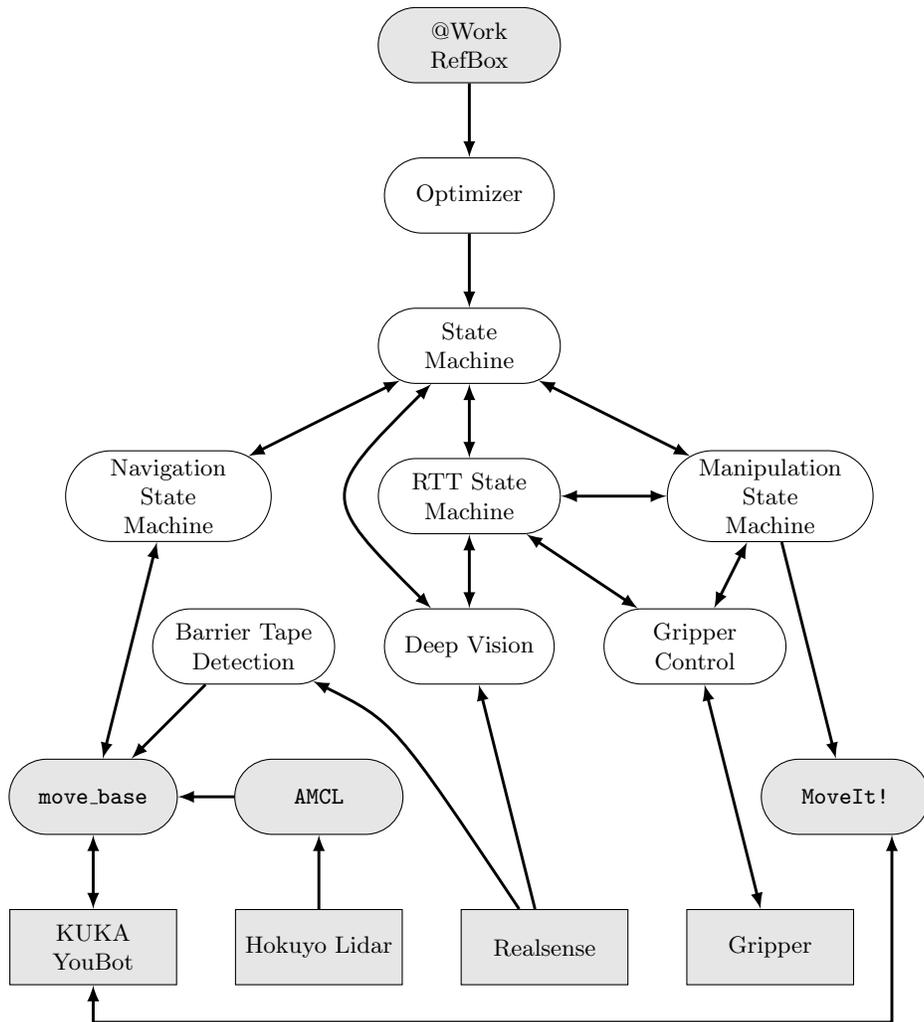


Fig. 2. Overview of the main software components of the robOTTO @Work framework.

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.

Deep-Learning-based Vision - Deep Vision We currently only use 2D images for object detection even though the realsense also provides 3D data. Our object detection system is based on the Tensorflow Object Detection API. We created a custom bootstrapping and augmentation system to generate additional training data. The major work in this system was the manual generation of training data. To ease the process we developed a custom tool to check the

detection and classification output and generate manually corrected training samples. To only addition to the original detection API is an additional object orientation detection code to also output a 2D rotation of the object on the workstation.

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)**[3] 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!** [2]. **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 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 overlaid 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

Fully Integrated Rotating Table Operations Changes in the RuleBook of the league [6] needed new behavior to handle grasping from the rotating table. The team already created new behavior including new detection mechanisms to handle the rotating table. However, the current approach is a cross-layer approach, which breaks the normal flow of control between the system components, as described in Section 4. Consequently, the current software works for the designated rotating table task as specified in the RuleBook [6]. To enable the rotating table operations also in normal tasks like the FINAL, an integration of the behavior is necessary, which needs a generalization of the current software architecture.

Graph-based Visual State-Machine Currently, the behavior of the robot is encoded in three state-machines, which control the actions necessary for navigation and manipulation as well as the general behavior to pick-up and place objects. However, these encodings are based on manually written C++-Code. This code is cumbersome to modify and also fails easily. However, in competitions the ability to quickly modify the state-machine is crucial. Consequently, we currently try to move our state-machines to FlexBE [8] to enable easy modifications and integrated testing of the encoded behaviors.

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.

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