DARKO
Dynamic Agile Production Robots That Learn and Optimise Knowledge and Operations

H2020-ICT-2020-2 Grant agreement no: 101017274

DELIVERABLE 1.1

Initial DARKO mobile dynamic manipulation platform

Dissemination Level: PUBLIC

Due date: month 14 (February 2022)
Deliverable type: Prototype
Lead beneficiary: TUM

1 Introduction

Deliverable 1.1 represents the initial DARKO mobile manipulator, which serves as the base for the research development in the first phase of the project. It is a customised mobile robot built from commercially available state-of-the-art components. The main effort has been on the selection of the mobile base as well as on the selection and integration of the sensors and the gripper based on the requirements of the individual DARKO subtasks.

2 Specification

In this section, we will focus on the following individual subsystems of the mobile manipulator:

- Mobile platform (Section 2.1)
- Fixed-base manipulator (Section 2.2)
- Gripper (Section 2.3)
- Sensors (Section 2.4)
- Additional customisation efforts (Section 2.5)

2.1 Mobile Platform

To select a suitable mobile platform for the DARKO project, a list of requirements based on the project tasks and use cases was compiled in close interaction with the partners. TUM has scheduled several meetings and the partners discussed the requirements. A visit to BSH (Bosch Hausgeräte) for better understanding of the use cases and the targeted objects to handle was planned and according to the output of the meetings, the following key performance indicators were selected:

- **Software Interface:** accessible Application Programming Interface (API) that exposes lower-level routines for whole-body control and sensor integration, full support for the ROS middleware including URDF model and real-time interfaces
- **Mobility:** Ability to operate on low slope ramps or obstacles, high maximum velocity
- **Operation and charging time:** Long running time with short charging time
- **Hardware:** Mounting options for different sensors and the developed elastic manipulator, possibility of having an emergency stop, enough power supply for additional devices such as PC/GPU, cameras
- **Pre-installed sensors:** Ideally, the platform already comes with odometry, lidar, sonar

TUM has made a comprehensive market analysis and among several options the Robotnik Kairos+ robot (Figure 1) comes with the following advantages over the other platforms: It has the highest speed and mobility among the shortlisted platforms (maximum velocity of 3 m/s, 40 mm ground clearance, 10 % slope climbing capability). At the same time, the operating time is long enough for the task requirements (8 h) and it provides current-level access of the drive unit. The robot comes with some of the required sensors and Robotnik offered an integration service for the rest of required sensors and gripper. Therefore,

Figure 1: The selected Robotnik Kairos+ mobile base.

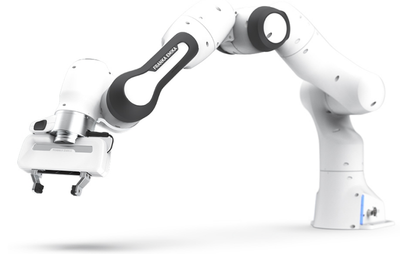

Figure 2: Franka Emika Panda as the fixed base manipulator for the first phase of the project.

Kairos+ from Robotnik company was selected as the Darko mobile base and the fixed-base manipulator, gripper, and additional sensors required from WP2 (perception) and WP3 (mapping), as indicated in D8.1, were fully integrated by Robotnik.

2.2 Fixed-base Manipulator

In T1.3, an elastic arm will be developed and mounted over the mobile platform in the second phase of the project; however in the first phase an off-the-shelf manipulator should be used. The agile production use cases considered in the DARKO project require highly dynamic manipulation skills, such as grasping and throwing moving objects (WP4 and WP6). For this reason, a lightweight, energy-efficient, and torque-controllable fixed-base manipulator that is able to measure the contact forces for the grasping task is required. Furthermore, the consortium agreed to use ROS as the main common development base. The Franka Emika Panda platform (Figure 2) is already widely used within the consortium and fulfills all of these requirements. Therefore, it was selected as the initial fixed-base manipulator.

2.3 Gripper

T1.2 is dedicated to the development of a general-purpose gripper, which should be built up during the first 2–3 years of the project. For the first phase of the project, an off-the-shelf gripper, which meets the project requirements had to be selected. The necessity of doing dynamic manipulation tasks such as grasping and throwing objects posed a major challenge in selecting a suitable initial gripper. Additionally, the gripper had to be compatible with the shape, texture, and elasticity of the kind of objects considered in DARKO (home appliance spare parts). Two main groups of grippers were shortlisted: multi-finger-adaptive-grippers and vacuum-grippers.

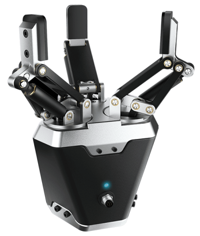

Figure 3: DH-3 multifinger gripper selected for the use in the first phase of the project.

Based on the project requirements, the following key performance indicators were selected:

- Load capacity
- Mass
- Power consumption
- Closing and releasing time
- Compatibility with Franka Emika Panda
- Possibility of grasping objects of Darko use cases

TUM has made an extensive market analysis to decide about the gripper. Obtaining the necessary information for each available gripper was a challenging task since commercial grippers are commonly used for quasi-static motions and there is no standard for such metrics. The available existing experience within the consortium was also taken into account to select the best solution. DH Robotics' DH-3 multi-finger gripper was the closest option, which met the minimum requirements specially due to its adaptability and load capacity. It is worth mentioning that the previous experience of one of the partners in WP4 (Efficient and Safe Dynamic Manipulation) strongly supported this decision.

2.4 Sensors

In close collaboration with partners from WP2, WP3 and WP4, a list of the preferred sensors for the robot was compiled. The consortium has decided to select the following list to facilitate object-level semantics, which relies on sensor fusion of a set of various optical sensors with different fields of view including:

- 2 x Azure Kinect cameras, one equipped with a custom pan/tilt unit
- Ouster OS0 Lidar
- 2 x Basler Ace Cameras
- Intel RealSense D435 Camera

The Ouster OS0 Lidar and Basler Ace Cameras provide a larger field of view for the general 3D-scene understanding. The Azure Kinect cameras are used for this purpose as well, but also in particular to detect the objects that are supposed to be grasped and thrown. DARKO may require to grasp/throw objects in motion or objects that are very tightly stacked. It is therefore important to carefully plan the placement of the sensors in order to minimise occlusion. The manipulator was placed in the front-right corner of the robot. The lidar and

Figure 4: The final DARKO mobile robot equipped with the Panda robot, the gripper and the required sensors in the position of grasping objects from lower and higher shelves.

the fish-eye cameras are placed diagonally, on the opposite corner, and the Azure Kinect is placed on the same side as the manipulator across the lidar. Using such a configuration also facilitates grasping from lower and higher shelves (Figure 4). An additional Intel RealSense D435 camera is placed on top of the manipulator.

To meet the safety requirements for WP4, the robot was additionally equipped with Sick Microscan safety cameras with a Sick Flexisoft safety PLC as well as a wireless emergency stop. Robotnik provided a key-ready solution with all sensor drivers installed.

2.5 Additional Customization efforts

2.5.1 Additional computational resources

Real-time perception with semantic and geometric understanding of the scene as well as moving humans and objects places high demands on the computational power of the system. To extend the computational capacity of the robot, an *Nvidia Jetson Xavier* and a *Nuvo-8108GC XL CPU* were integrated into the robot. An overview of all available computers and sensors is shown in Figure 5.

2.5.2 Communication of robot intent

WP5 focuses on human-robot spatial interaction (HRSI). For HRSI to be safe and smooth, it is paramount to communicate the robot's motion and intention to humans in its close proximity. One way of ensuring safe and smooth HRSI that we wish to research in the DARKO project (T5.2) is to leverage anthropomorphic social signaling with a humanoid robot. For this task we are using Aldebaran Robotics' Nao platform, seated on top of Örebro University's mobile platform – to be able to communicate with human-like gestures. Örebro University (ORU) have 3D-printed a custom seat for the Nao robot and mounted it on top of the mobile base.

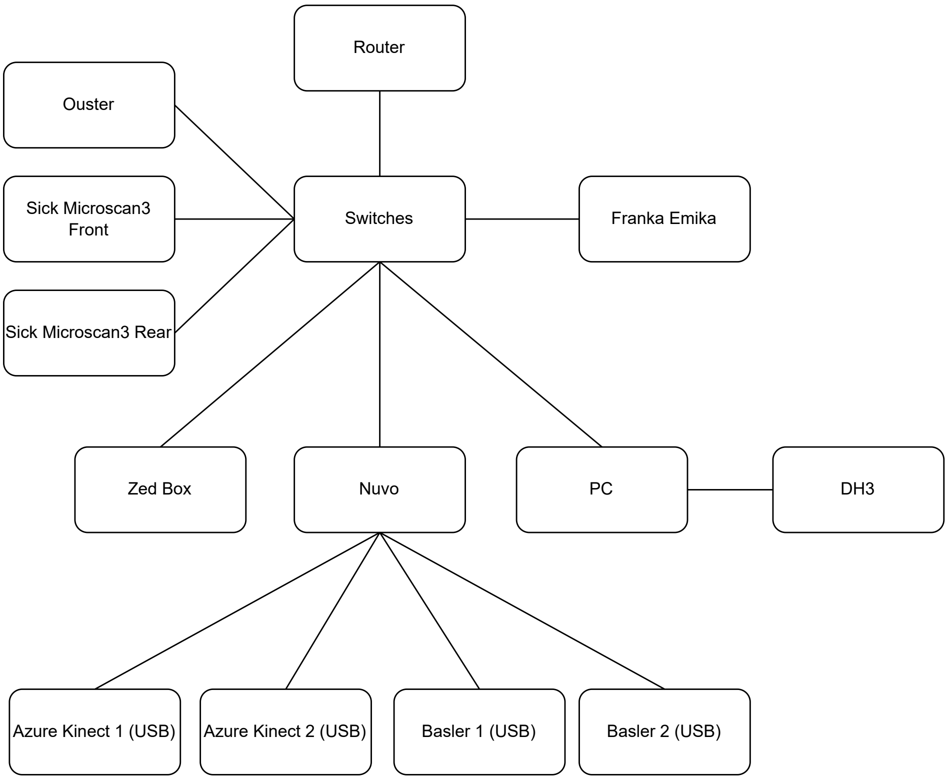

Figure 5: Network overview, in this chart communication network of the integrated components into the Kairos platform can be seen.

Figure 6: Humanoid robot Nao used to leverage anthropomorphic social signaling and ensure safe and smooth HRSI.

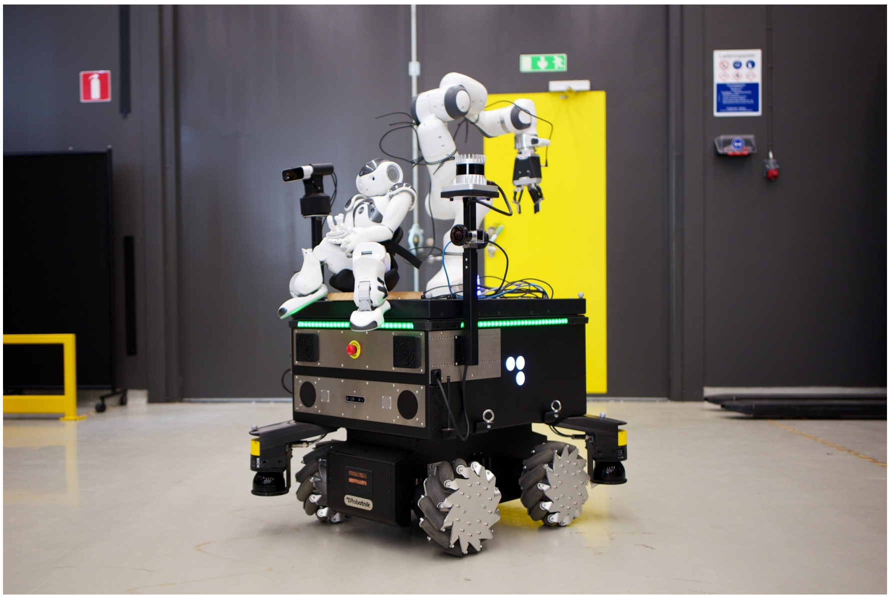

Figure 7: The first DARKO mobile manipulator unit (ORU) with a Nao robot on the platform

Figure 8: The second DARKO mobile manipulator unit (UNIPI)

3 The three customized robots

According to the partner requirements and their scope of the work, the budget for the purchases of three DARKO mobile manipulators was planned in the grant agreement. These three mobile manipulators have been purchased by TUM, ORU, and UNIPI, and will be shared with the rest of the partners for research purposes. The ORU unit will be located at the ARENA2036 demo site for the most part of DARKO.

All three robots have similar configuration, but there are a few minor differences due to the requirements of each WP and the responsible partner. TUM as the leader of WP1 (Efficient Mobile Dynamic Manipulation Platform (RTD)) has the role of developing an elastic arm and the integration of the arm with the mobile base. Therefore, TUM has decided to purchase a standard setup including all modules and sensors presented in this document. UNIPI as the leader of WP4 (Efficient and Safe Dynamic Manipulation) is mainly focused on the arm manipulation. Thus, it was unnecessary to equip their robot with an Ouster OS0 Lidar, which saves some budget for UNIPI to spend in other tasks (e. g. T1.2, which is about the development of a general-purpose gripper). Therefore, UNIPI's robot include all the discussed modules and sensors except the Ouster OS0 Lidar. ORU as the leader of WP3 (Multimodal Mapping and Safe Localization) and a main contributor to WP5 (Human-Robot Spatial Interaction) needs all the standards sensors including Ouster OS0 Lidar, which is necessary for the development of the main consolidated map representation that is used for navigation and planning. As mentioned above, for the HRSI and intent communication, ORU's mobile manipulator also has an Aldebaran Robotics' Nao platform.

Regardless of these minor differences, the three institutes ordered their robots together and received their systems (Figures 7 and 8). It is worth mentioning that due to the shortage of electronic parts in the market there was a long delay in delivery of the robots.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101017274