Omnidirectional Mobile Manipulator LeoBot for Research and Teaching in Industrial Environments: Supplementary material *

Martin Sereinig, Peter Manzl, Patrick Hofmann, Rene Neurauter, Michael Pieber, and Johannes Gerstmayr

Department of Mechatronics, University of Innsbruck, Technikerstr. 13, 6020 Innsbruck, Austria martin.sereinig@uibk.ac.at
https://www.uibk.ac.at/mechatronik/mekt/

Abstract. This document contains supplementary materials for the paper "Omnidirectional Mobile Manipulator LeoBot for Industiral Environments, Developed for Research and Teaching" published at the RoboCup-world cup in Bankok 2022 .

Keywords: Robotics · University of Innsbruck · RoboCup@Work · RoboCup · Tyrolics · Mobile Manipulator · Object Recognition · Mechatronic Design · Redundant Robot · Real-time Control · Franka Emika Panda · Mecanum wheels · Multibody Dynamics · Flexible Multibody Simulation · Simulation Framework Exudyn.

1 Introduction

This supplementary material includes drawings, figures and tables to complete information about the mobile manipulator LeoBot developed by the RoboCup@Work team TYROLICS from the University of Innsbruck. The team started as a cross-location project at the University of Innsbruck and was founded in 2019. The idea was born in the research group for Machine Elements and Design of the Department of Mechatronics which is a part of the Faculty of Engineering Sciences. The research focus of the group is on theoretical, numerical and experimental problems in the field of multibody system dynamics, such as robots, machine tools or hybrid vehicles which constitute a fundamental part of every mechatronic system. The presented system costs approx. 38000 Euros and is thus low-cost compared to equivalent commercial system within Table 1 the costs of the individual components can be found.

* Supported by the University of Innsbruck.

Table 1: Overview of the general hardware costs.

Matter of expense	Quantity	Unit price (EUR)	Total price (EUR)
Gear (GP32C) and motor (Maxon EC-i30)	4	460	1840
Motor controller (EPOS4 50/15 EtherCAT)	4	460	1840
Mecanum-wheels (NM152A)	4	200	800
Mechanical material (screws, nuts, bolts etc.)	-	-	500
Production (CNC Machine, technicians)	-	-	1500
Miscellaneous (cables, connectors, relais etc.)	-	-	500
Franka Emika Panda	1	23350	23350
Sick Laser System (TIM7xx)	2	1500	3000
Sick Laser Safety PC (Flexisoft FX3)	1	2000	2000
Power electronics	1	559	559
Internal computer running Ubuntu 18.04	1	1000	1000
Nvidia Jetson Nano, GPU	1	200	200
Battery	2	400	800
3D-Camera Intel Realsene (D415)	1	200	200
3D-Camera Intel Realsene (D435i)	1	200	200
Sum		**38289**	

2 LeoBot Mechanical components and construction

Important mounting points as well as overall dimensions of the mobile manipulator without gripper can be seen in Fig. 2. The wheels are mounted inside the platforms footprint to enable a 360° view with two Lidar Scanners, which are mounted close the the ground to detect obstacles lager than 3cm in height. General construction calculations are following [2].

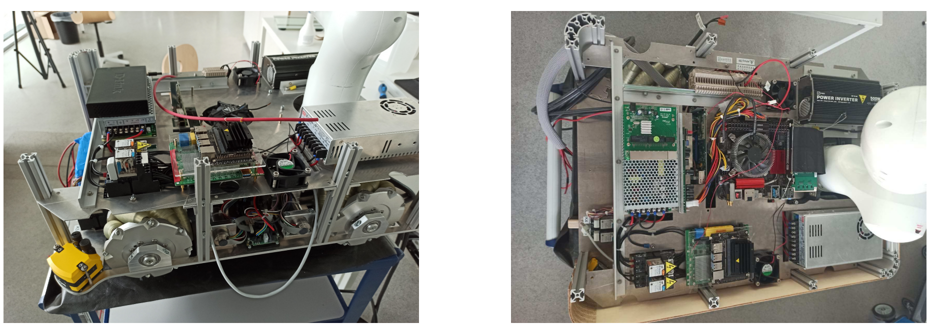


Fig. 1: Mobile manipulator LeoBot side view (left) and top view (right) without electric wiring and cable connections.

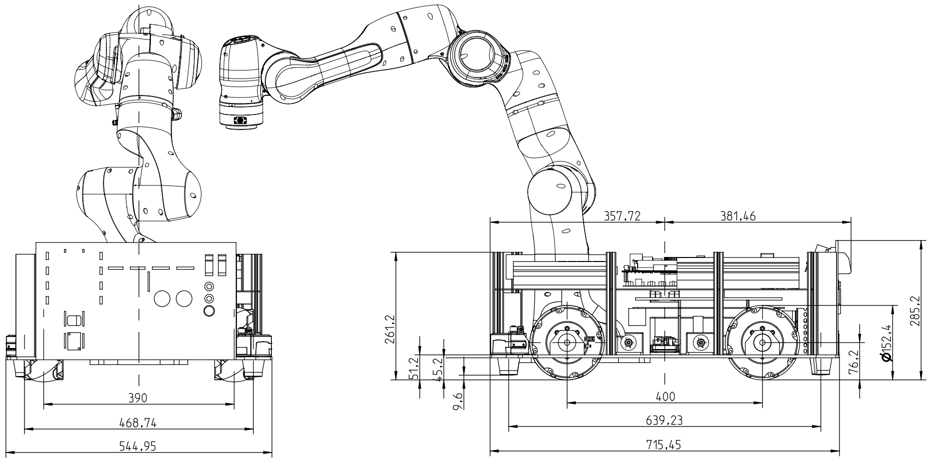


Fig. 2: Dimensions of the mobile manipulator LeoBot.

2.1 Drive Unit and Mecanum wheels

The mobile platform is driven by four Mecanum wheels to achieve omnidirectional movement. Each wheel is controlled independantly and no steering system is needed. This results in a moving base with three degrees of freedom. Therefore a motor-wheel-gear assembly group was developed and four of this assembly groups are needed to drive the platform. Fig. 3 shows the drive assembly group with its dimensions in two different views and Fig. 4 shows the individual components including a parts list. As co-axial mounting of wheelhub and electric motor is not possible due to limited space, we utilized a timing belt allowing for parallel mounting of the latter components. Additionally, the pulleys of the belt drive can be changed to adjust the gear ratio and thus torque and velocity. Further, the position of the motor mount is adjustable to satisfy required timing belt tension. The axles and the Mecanum wheels are held by an interference fit.

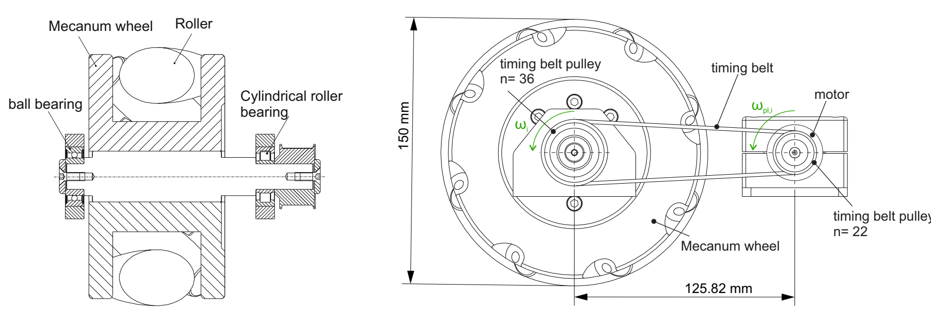
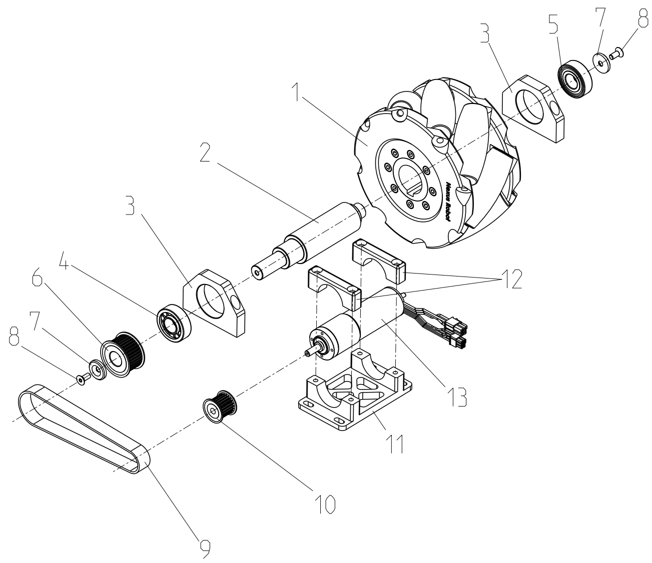


Fig. 3: Mecanum wheels axis, bearings and drive unit overview.

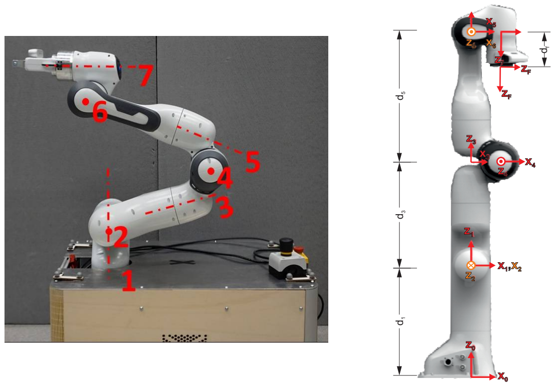


Number	Information
1	Mecanum wheel
2	Wheel axle
3	Bearing box
4	Ball bearing
5	Cylinder ball bearing
6	Pully small
7	Washer
8	Screw
9	Belt
10	Pully large
11	Base motor mount
12	Motor mount clamps
13	Electric Motor

Fig. 4: CAD design of drive-gear assembly group including mecanum wheel and timing-belt construction as explosion drawing.

3 Franka Emika Panda Serial Manipulator

A Franka Emika Panda Serial Manipulator is used for interaction with the environment. With a reach of 855 mm and 7 degrees of freedom and torque control



i	a_i	α_i	d_i	θ_i
1	0	0	d_1	q_1
2	0	$-\pi/2$	0	q_2
3	0	$\pi/2$	d_3	q_3
4	a_4	$\pi/2$	0	q_4
5	a_5	$-\pi/2$	d_5	q_5
6	0	$\pi/2$	0	q_6
7	a_7	$0\pi/2$	0	q_7
8	0	0	d_1	0

Fig. 5: Manipulator with 7DOF and additional panda hand as end effector (left). Modified Denavid-Hartenberg frames with $d_1 = 0.333$m, $d_3 = 0.316$m, $d_5 = 0.384$m, $d_f = 0.107$m, $a_4 = 0.0825$m, $a_5 = -0.0825$m and $a_7 = 0.088$m (center). Modified Denavid-Hartenberg parameters (right)[1].

it is well suited for the typical industrial challenges, demanded at the RoboCup@Work while the sensitivity of the integrated collision detection makes it safe to operate. Integration into the Robot Operating System is available for the Panda.

4 Electronics

All components used are arranged on three layers as well as on the back plate as shown in Fig. 6. Fig. 7 shows the mobile robot disassembled into three parts for maintenance. In the marked area (1) the back plate where all sockets and switches are placed is shown, on the inside of the back plate all fuses according to the wiring diagram in Fig. 8 are installed. Area (2) shows level 2 including the main computer unit and the WAGO connection panel as well as the Nvidia Jetson computer unit, the DC/AC converter and the 5VDC converter. Area (3) shows layer 0 and layer 1 including the SICK safety PLC, the motor-gear-wheel assembly group as well as the Franka Emika Panda controller.

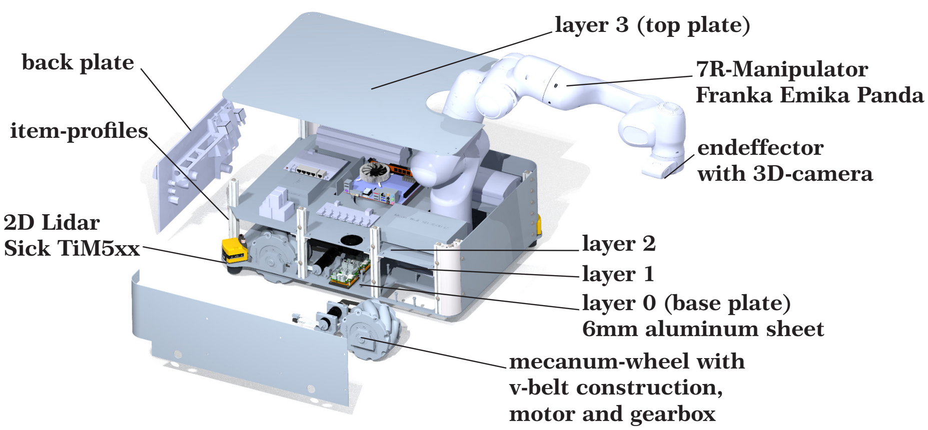


Fig. 6: LeoBot components overview and layer structure.

Three different types of wiring cables are used for the electronic components. The 12 V and 5 V circuits uses a 2.5mm^2 hight flexible where a maximum current of up to 26A as descibed in DIN EN 60228 is allowed. The power cables connecting the battery to the dc/dc and dc/ac converters are build of 4mm^2 cabels which allows maximum currents up to 34A. Furthermore for all digital communication connection the needed cables are used as required from the used technology (e.g. USB, LAN, ...). The electronics wiring diagram is separated into three parts and additional all data connections (USB, LAN, EtherCat) are shown in Fig. 11.

Fig. 8 shows the wiring diagram for all main electronic components. This includes the 5VDC, 12VDC and 220VAC circuits. Each electronic device is also

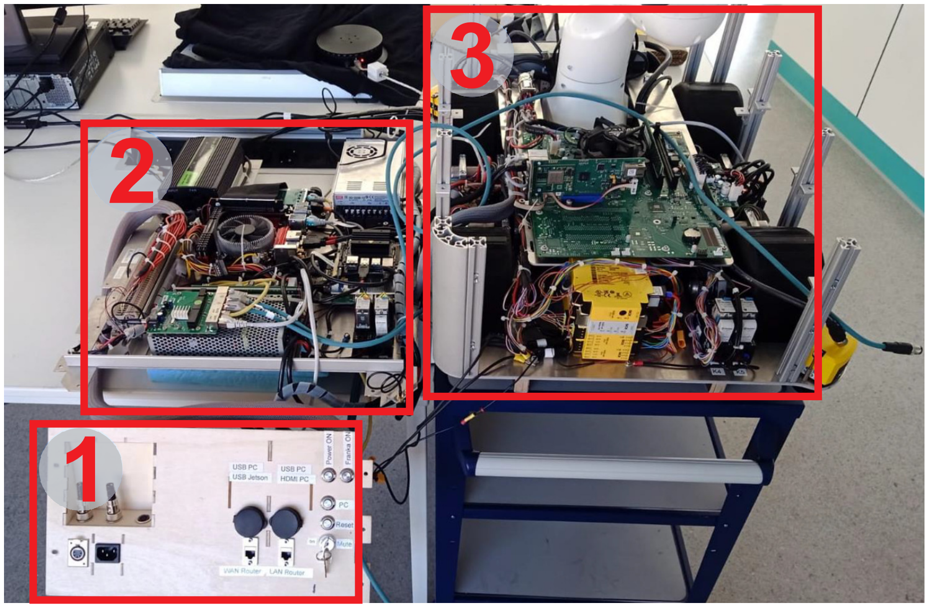


Fig. 7: LeoBot separated into three parts with back plate (1), layer 2 (2) and main platform including layer 0 and layer 1 (3).

secured by a individual fuse which can easy be changes by disable the back plate (see Fig. 7) (area 1).

The safety system of the mobile platform LeoBot is based on products form the company SICK. Fig. 9 shows the wiring of those components. The EN ISO 13849 safety norm for machinery control systems is used and the safety categories (b, 1, 2, 3 and 4) are described there. Fig. 11 shows the connections between the SICK components and the rest of the system. The SICK laser scanners are rated as safety category B and the input/output-module as well as the used CPU is rated as safety category 4. The used categories as mentioned in EN ISO 13849 defines the classification of safety-related parts regarding to their structure, fault detection or reliability and quality. Possible categories are B,1,2,3 and 4 whereby category B and 1 does not include any diagnosis functionality, category 2 includes mandatory testings, category 3 needs additional diagnosis and robust design (2 channel interfaces) and category 4 needs additional additional high difficult diagnosis tests and redundant system designs. The B_{10d} value indicates the switch count where 10% of all used products archive a dangerous malfunction. 10 shows the wiring of one maxon EPOS4 with one maxon motor[1].

[1] Maxon motor-gear-encoder combination, EC-i30- 75W motor with GP32C 33:1 planetary gear and ENC16RIO4096 incremental encoder

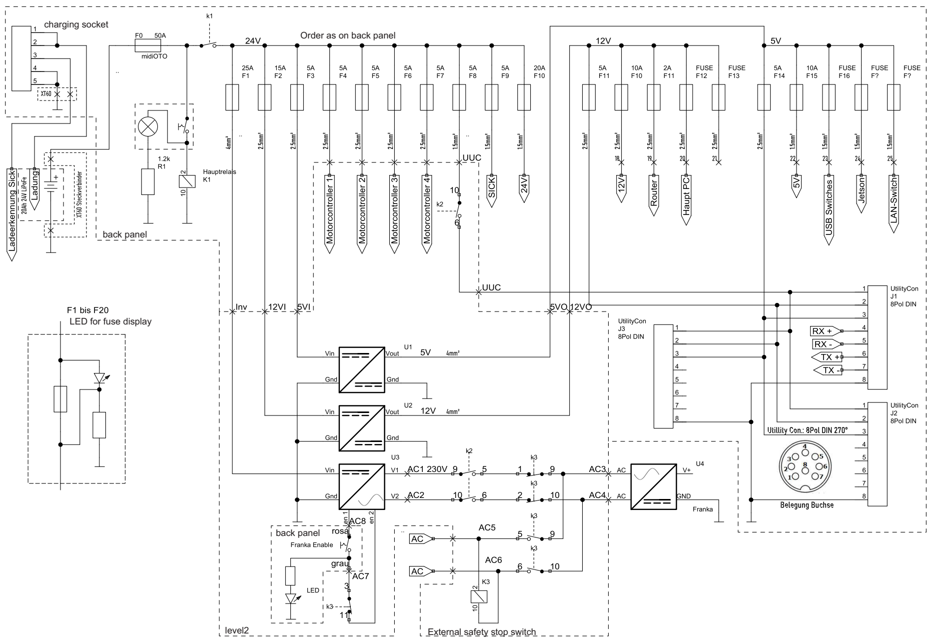


Fig. 8: Wiring diagram for all main electronics.

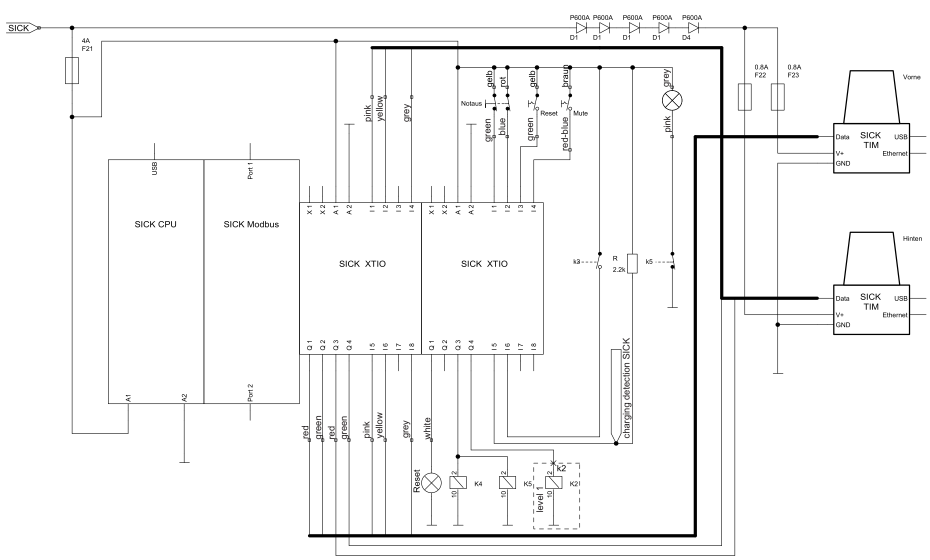


Fig. 9: Wiring diagram for the SICK safety components.

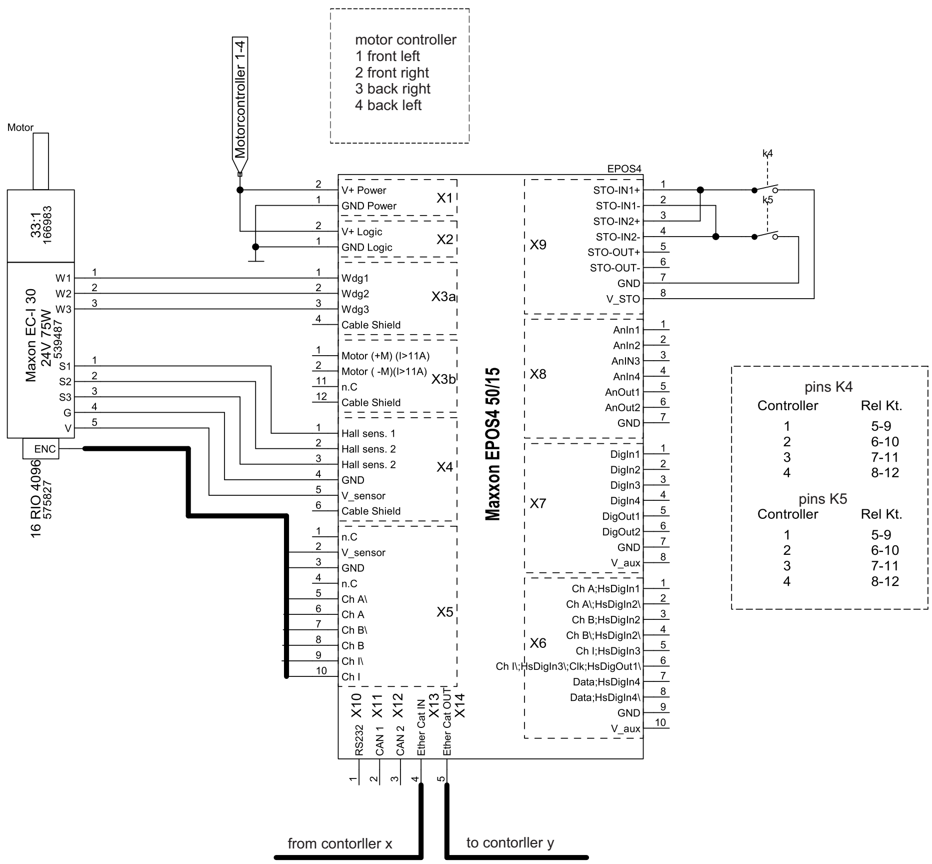


Fig. 10: Wiring diagram for maxon EPOS 4 motor controller.

5 LeoBot Software developments

Software developments made within the RoboCup@Work team tyrolics project and used with the mobile manipulator LeoBot can be found on the GIT repository https://github.com/leobot-UIBK/LeoBotRoboCup, which is licenced under the BSD 3-Clause "New" or "Revised" License. The main software software packages are shown in Table 2 as well as the responsible creator. In Fig. 12 the basic structure of the communication in the Robot Operating System is shown.

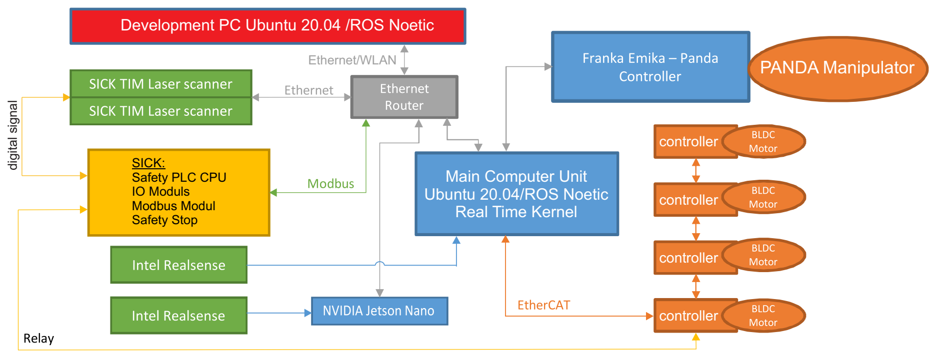


Fig. 11: Communication structure with computation units (blue), sensors (green), safety components (yellow), actuators (orange) and development PC (red).

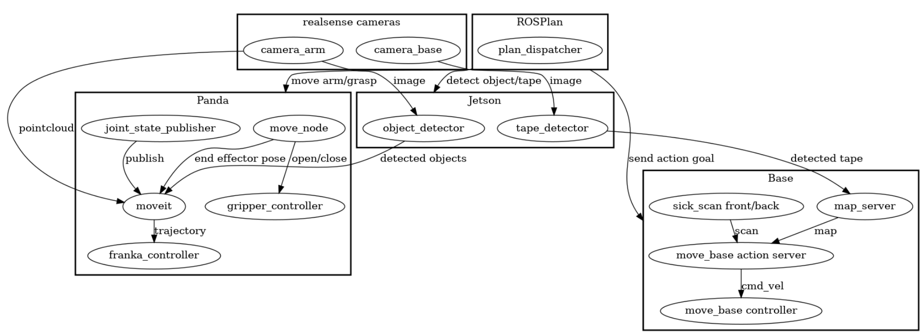


Fig. 12: Ros Nodes architecture.

Table 2: Overview of currently used software packages.

Software package	Responsible developer	Information
epos_ethercat	Peter Manzl	EPOS motor controllers interface
franka_controllers	Patrick Hofmann	Franka Emika Panda interface
franka_movement	Patrick Hofmann	MoveIT interface
franka_ros	Patrick Hofmann	Franka Control interface
ira_laser_tools	Burkhard Moser	Point cloud merger
leobot_config	Peter Manzl	Launch and config files
leobot_safety	Burkhard Moser	ROS Modbus Interface
meassurements	Peter Manzl	Interface for measurement data
panda_moveit_config	Patrick Hoffmann	MoveIt! configuration
panda_test_move	Martin Sereinig	Interface to Moveit from Python node
precition_placement	Patrick Hofmann	Precition placement test
qr_position	Martin Sereinig	QR code detection
robocup_msgs	Patrick Hofmann	Custom messages
sic_scan	Burkhard Moser	SICK TIM Laser Scanner Interface
sim_ros_interface	Patrick Hofmann	Coppellia Simulation Interface for ROS
vicon_bridge	Martin Sereinig	Vicon motion capture system
vicon_position	Martin Sereinig	Position controller using vicon data

References

1. Gaz, C., Cognetti, M., Oliva, A., Giordano, P.R., De Luca, A.: Dynamic identification of the franka emika panda robot with retrieval of feasible parameters using penalty-based optimization. IEEE Robotics and Automation Letters **4**(4), 4147–4154 (2019). https://doi.org/10.1109/LRA.2019.2931248
2. Mott, R.: Machine Elements in Mechanical Design. Pearson/Prentice Hall (2004)