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Human-centered manipulation and navigation with Robot DE NIRO

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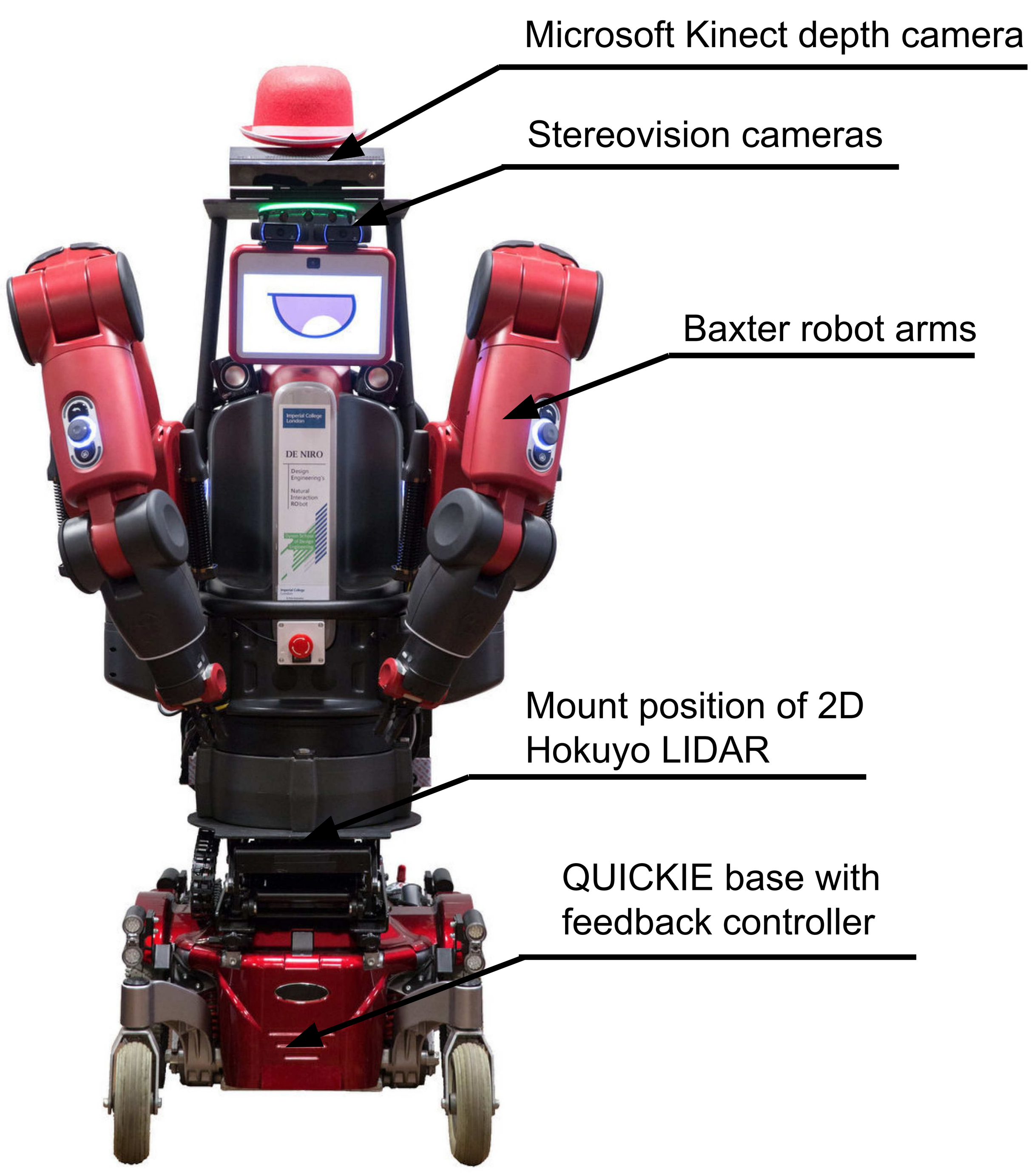
Summary

We present **Robot DE NIRO** (**D**esign **E**ngineering's **N**atural **I**nteraction **Ro**bot), a collaborative research platform for mobile manipulation. Given the macrosocial trends of aging and long-lived populations, robotics-based care research mainly focused on helping the elderly live independently [1] [2]. In contrast, DE NIRO aims to support the supporter (the caregiver) and also offers direct human-robot interaction for the care recipient.

Hardware Design

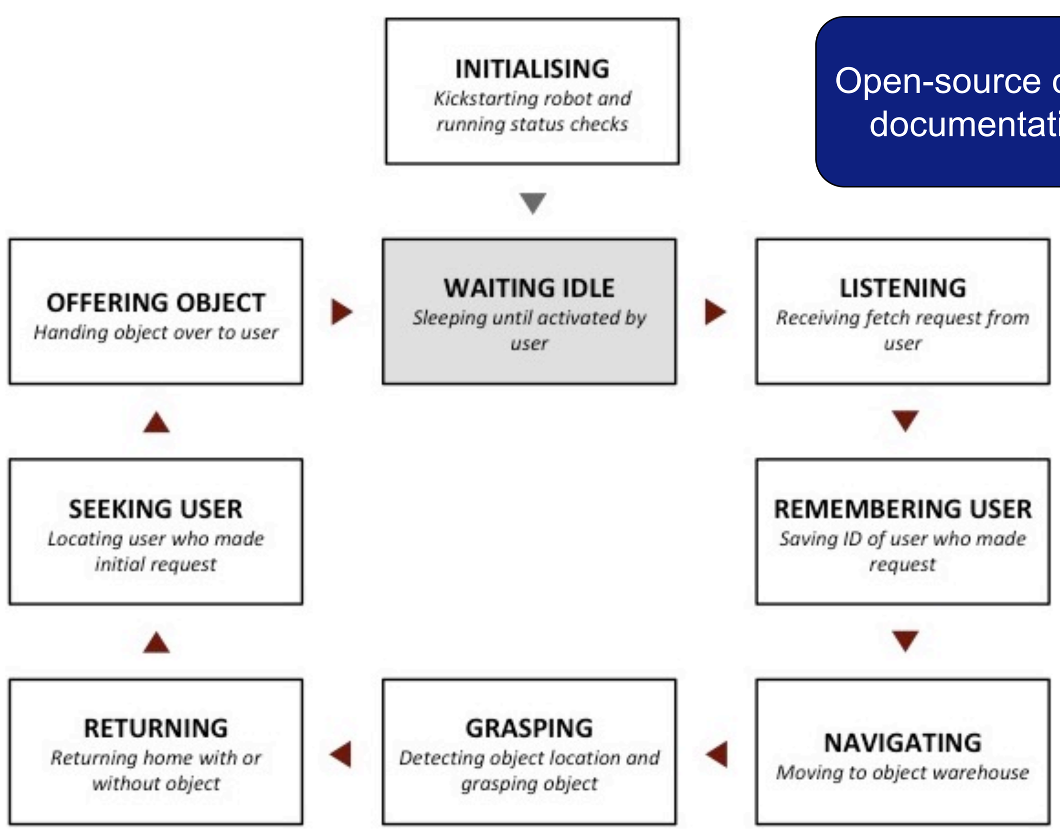
DE NIRO's core design idea is to combine the industrial Baxter dual robot arms with autonomous navigation into a mobile manipulation research platform. It is equipped with a variety of actuators and sensors depicted below, of which shall be highlighted:

- **Baxter dual robot arms**: Passive compliance through series elastic actuators are a particular safety feature, allowing the robot to interact with humans in close proximity, since in the case of a contact, most of the physical impact is absorbed.
- **QUICKIE base**: Differential drive operated with a custom PID angular position and velocity controller, allowing primitive motion commands for navigation [3].
- **Microsoft Kinect RGB-D camera**: High-resolution depth camera.
- **2D Hokuyo LIDAR**: Industrial standard laser scanner capable of mapping and localization.



Software Implementation

In designing DE NIRO, we have put an emphasis on natural and safe human-robot interaction procedures across multiple components, including speech and face recognition and collision avoidance. To handle concurrent execution and both synchronous and asynchronous communication between components, we use **Robot Operating System (ROS)** as a middleware. We define distinct functionalities of the robot with a **finite-state machine** depicted below, such as *listening* (for command input) or *grasping* (to physically pick up an object). The state machine handles the control flow among these states.



Open-source code, documentation

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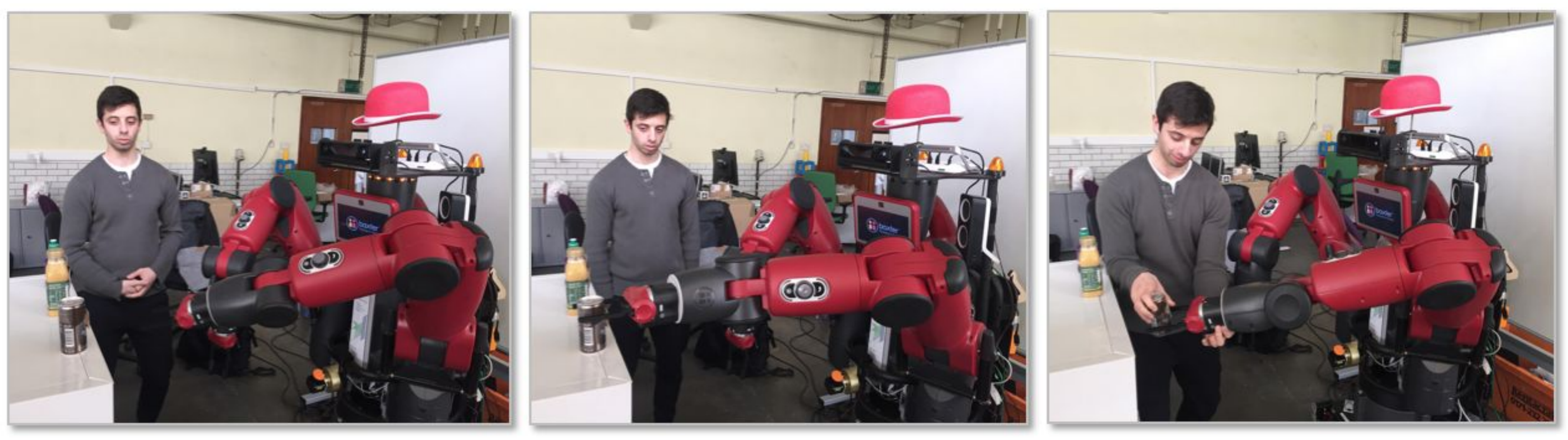
Object Recognition and Manipulation

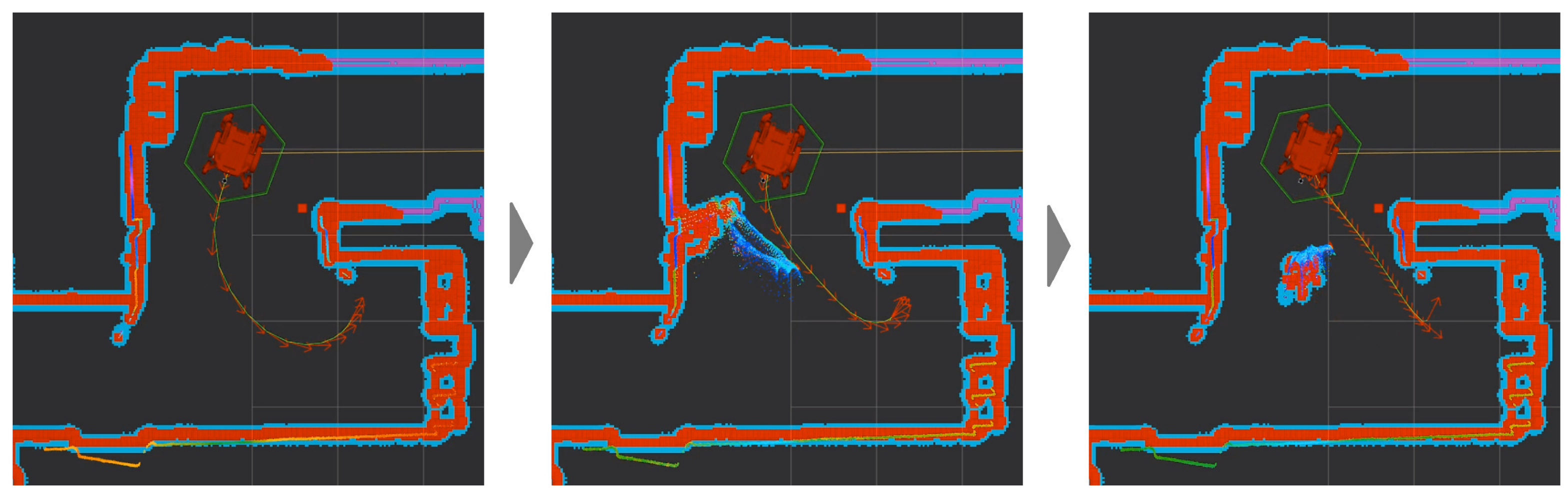
- Target objects are localized using **2D fiducial markers** [5].
- To control the Baxter arms, we employ an **inverse kinematics solver** to compute each of the seven joint angle trajectories needed to reach an object [6].
- A **dynamic awareness procedure** reacts to changes of the location of the target object during grasping and actively avoids collisions.



Navigation, Mapping and Planning

A navigation stack consisting of mapping, localization and trajectory planning was implemented (illustrated below).

- **Static mapping**: We apply a SLAM-based approach to the LIDAR sensor in order to detect any spatial boundaries and 2D artifacts in a predefined space [4].
- **Localization**: Overlaying a dynamic map onto a static map to detect obstacles for collision avoidance. A costmap is imposed as a virtual cushion for additional safety.
- **Trajectory planning**: "Timed elastic band" approach, conceiving of trajectory planning as a multi-objective optimization problem [7] [8].



Perception and user interaction

For a natural interaction with the user, we implemented face and speech recognition.

- **Face recognition**: A *ResNet* model pre-trained on faces was applied to video frames retrieved by the Kinect camera, reaching an accuracy of 99.38% on a standard benchmark [9]. The model compares the output vector encodings of known faces with those extracted from processed frames by computing a distance metric.
- **Speech recognition**: The offline library *CMU Sphinx* was implemented [10]. We defined a *Jspeech Grammar* to allow reliable voice commands in a specific format and automatically calibrate to background noise levels.
- **Speech output**: *eSpeak* [11] yielding a high reliability, rapid response time and an offline implementation.

Conclusion

- **Limitations**: nonholonomic design; maximum payload of 2.2 kg per arm; currently limited to forward motion only due to limited sensor capabilities
- **Future work**: increased awareness and safety through 360-degree camera rig; 3D LIDAR; more robust localization without predefined mapping; teleoperation through virtual reality headset and body tracking markers

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