Cheap or Robust?
SLAM, DATMO, and the Development of Practical Self-Driving Assistive Robotics

International Workshop on Cooperative Dynamic Simultaneous Localization and Mapping

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Space & Terrestrial Autonomous Robotic Systems

- Research at the nexus of robotic sensing, planning, and control, focussing on problems related to representation and understanding of the world
  - Goal is to build **power-on-and-go** machines that are able to operate independently and safely over long time spans
- Current projects include:
  - Active perception for autonomous mobile manipulation in human-centred environments
  - Automatic spatiotemporal self-calibration of sensor pairs for high accuracy data fusion
  - *Development of low-cost, self-driving assistive devices (e.g., a self-driving power wheelchair)*

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Assistive Power Wheelchairs: Then

- First power wheelchair was developed by George Klein of the National Research Council of Canada in 1950's, to assist injured veterans returning from World War II

Assistive Power Wheelchairs: Now

- Since the 1950's, there have been advances in battery technology, motor design, basic control hardware, suspension components, …

  - Images on the right are of two chairs now on the market (Pride Mobility, Permobile), different price categories

- However, *these chairs still use the same basic technology as used in the 50's!*

  - For example, the Pride chair uses *open loop control*—there are *no* motor encoders included so the machine doesn't know when wheels are spinning or stuck

  - Aside from a basic motor control board and charging circuit, there isn't too much going on…

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Target Population: Upper Body Mobility Impaired

- There are more than an estimated **200,000** individuals in North America alone who are unable to operate a power chair with the standard joystick
    - Persons with: spinal cord injury (quadriplegia), MS, ALS, hand tremor due to Parkinson's disease, etc.
- These individuals are relegated to use other (archaic) input devices to control their chairs
    - Head trackers (given head mobility)
    - Eye gaze tracking (with eye control)
    - Sip-and-puff switches…
        - *Literally a straw that measure force*
- Worse, even joystick control is difficult and requires training and practice!

Self-Driving Power Chairs? Where are They?

- The idea of self-driving power chairs is *not* new, dating to at least the early 1980's

- Many chairs have been developed in research labs around the world, to test a variety of sensing, control and other algorithms

- **Almost without exception**, these chairs have used expensive sensing technologies, far out of reach of the average individual user…

  - Argument has been "prices will fall"

  - But mobility-impaired users need these devices *now*, not in 10 years' time…

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Cheap or Robust? Pick One...

- Traditional self-driving wheelchair tech has been either **cheap** or **robust**, but not both at the same time…

  - Which means it's either out of reach of any consumer (user who could benefit) in the near term, or not very useful

- We were approached (as a group with some expertise in vision and sensor calibration) by Cyberworks Robotics (partner) about **turning the standard equation on its head**:

  - Instead of asking what we can do with best sensing and computing (research problem)…

  - Ask, can we build a robust, marketable system for **< $3,000 CAD retail**?

- Different type of research problem—resource budgets, speed, lightweight but solid algorithms

$40K Sensing/Compute Budget

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$3K Sensing/Compute Budget

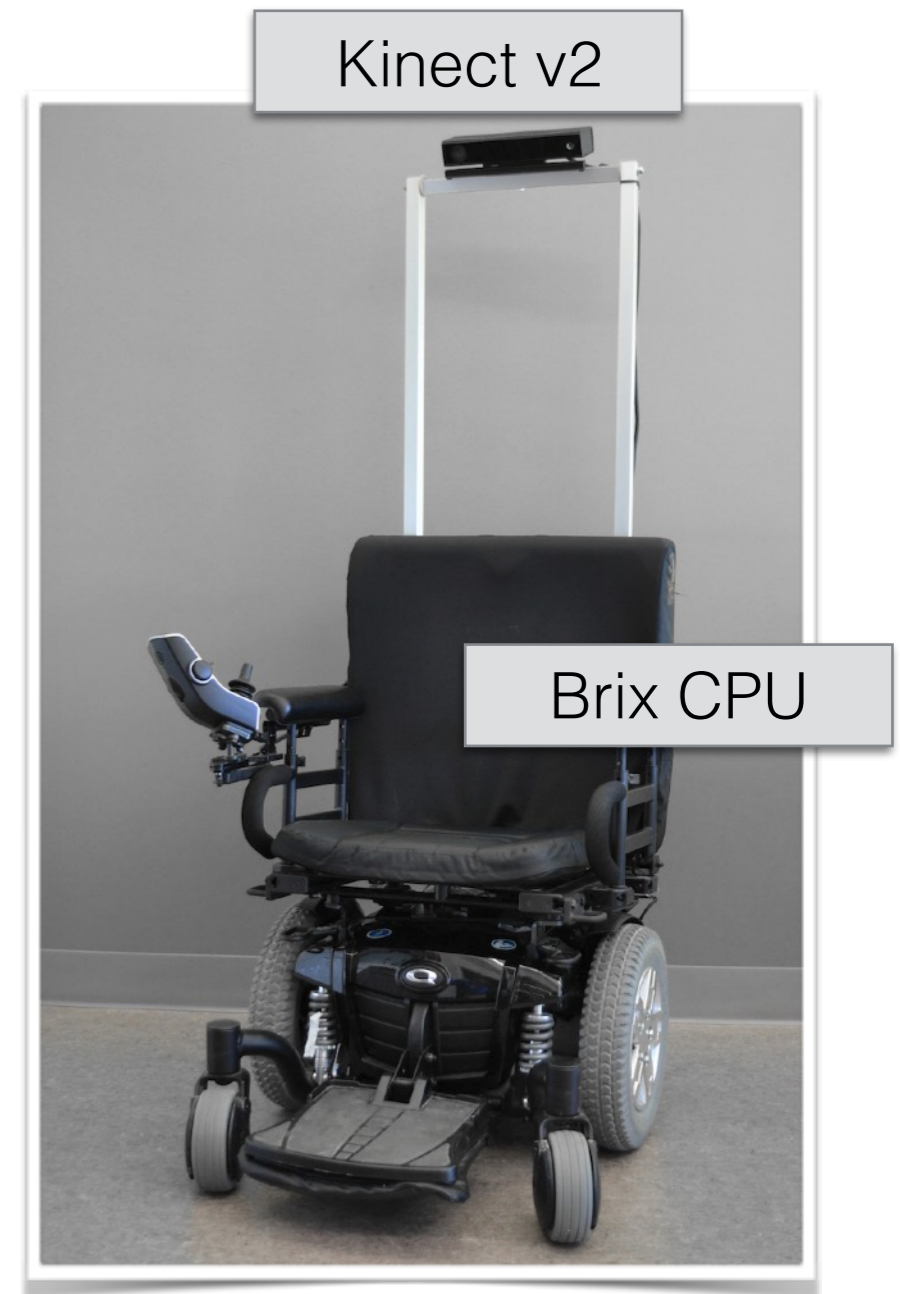UNIVERSITY OF
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Building a Low-Cost Add-On for Existing Chairs

- Should not be a custom (new) power chair, but rather a retrofit to existing chairs from many manufacturers
  - Installable by technician with 3-4 hrs. work
- Has to be *cheap*, so limited sensing / computing
  - One or two RGB-D cameras
  - MEMS IMU (optional)
  - Intel Core i7 CPU (16 GB RAM - Brix)
  - Wheel encoders on custom mounts
  - Interface hardware (to joystick port)

  _____

  Total Cost: $1,500 CAD (retail)

- All part are COTS (commercial off-the shelf) and readily available

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Encoders

What Capabilities are Required?

- Decided initially to focus on *indoor* environments only, where RGB-D sensing would be (mostly) reliable

  - Homes, care centres, office spaces, retail environments

- Started with a design study to define required capabilities:

  - Corridor-following (without an *a priori* map)

  - Doorway traversal (without an *a priori* map)

  - Desk docking (with or without a map)

  - *Full point-to-point navigation based on an existing map produced prior to deployment to an individual user*

    - By far the most challenging scenario

    - Key issues: obstacles and short- and long-term environment changes

Towards a Low-Cost Autonomous Wheelchair Navigation System Using COTS Components

Charlie Guan, Zeyang Wang, and Jonathan Kelly

I. OVERVIEW

Electric wheelchairs are often prescribed to individuals with mobility challenges. For a subset of users who have upper-body fine motor control impairments due to, for example, spinal cord injury, it is impossible to operate an electric wheelchair using the standard joystick interface. Such individuals must instead rely on other types of assistive control devices (e.g., sip-and-puff switches), which are typically extremely difficult to use. This results in degraded mobility and a substantially deteriorated quality of life.

A robotic navigation system for electric wheelchairs, which would allow the chairs to self-navigate in home and workplace environments, would dramatically improve users' mobility. However, at present, no widely available navigation system for wheelchairs exists, although the problem has been explored since the early 1980s [1]. Part of the reason is cost—much of the research to date has focused on the use of specialized sensing hardware. The prohibitive expense of such hardware makes the near-term, commercial deployment of a viable system unlikely.

Given significant recent advances in (inexpensive) navigation sensor technology and the continued maturation of open source robotics software, our research group recently asked the question: is it possible to build a reliable and low-cost autonomous or semi-autonomous wheelchair navigation platform using commercial-off-the-shelf (COTS) hardware and open source software only? In this extended abstract, we report on our initial progress towards answering this question by developing a prototype wheelchair navigation system.

II. SYSTEM DESCRIPTION AND CAPABILITIES

Our prototype navigation system (shown in Figure 1) is based on a standard commercial electric wheelchair, to which we have retrofitted a Kinect 2 sensor and related computing hardware. While previous research has focused on varying aspects of autonomy, including doorway traversal, wall following, and obstacle avoidance [2], modern simultaneous localization and mapping (SLAM) software enables the unification of these functions within a common navigation framework. We currently use the libfreenect2 open source library to acquire data from the Kinect 2. The second-generation Kinect has a 512 × 424 pixel time-of-flight depth sensor and a wide field of view full HD video camera. We also use wheel odometry

to aid in localization and mapping. All processing is carried out on a commodity laptop powered by an Intel i7 processor.

At present, we have implemented three main software capabilities: large-scale mapping, autonomous map-based navigation, and dynamic obstacle avoidance. We use the open source RTAB-Map as our SLAM package (running under ROS, the Robot Operating System) to build and maintain very large maps in semi-dynamic environments [3]. An initial map can easily be built by an operator in real-time, by manually guiding the wheelchair to visit all locations where the platform will be expected to drive. During the mapping process, RTAB-Map uses odometry information to assemble successive point clouds captured by the depth sensor into a 3D map (see Figure 2), and also renders this map into a 2D floor plan. This floor plan must then be validated by the operator and corrected, if necessary, using a custom, touch-enabled, web interface currently in development. The RTAB-Map software also continually captures RGB images and extracts visual features that are stored for future lookup to aid in localization and loop closure.

For autonomous navigation and obstacle avoidance, we employ the standard ROS navigation stack. The stack ships with a capable global path planner, which uses the 2D floor

Fig. 1. A commercial electric power wheelchair with the Kinect 2 sensor mounted above the backrest, ensuring a wide field of view.

The authors are with the STARS Laboratory, Institute for Aerospace Studies, University of Toronto.

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Deployment Scenarios

- Out-of-box, system is able to carry out corridor-following, doorway traversal, and basic desk docking—could be deployed immediately

- In more common scenario, occupational therapist working with patient (or technician) would travel to, e.g., person's care home and enable **mapping mode**, to build an initial map of all the areas in which the chair may travel

  - This map can be labelled with common destination (e.g., dining hall)

- For this point on, chair operates in localization mode, driving from place to place on command (autonomously)

- When significant environment change is detected, chair can enter **remapping** mode to make updates to existing map
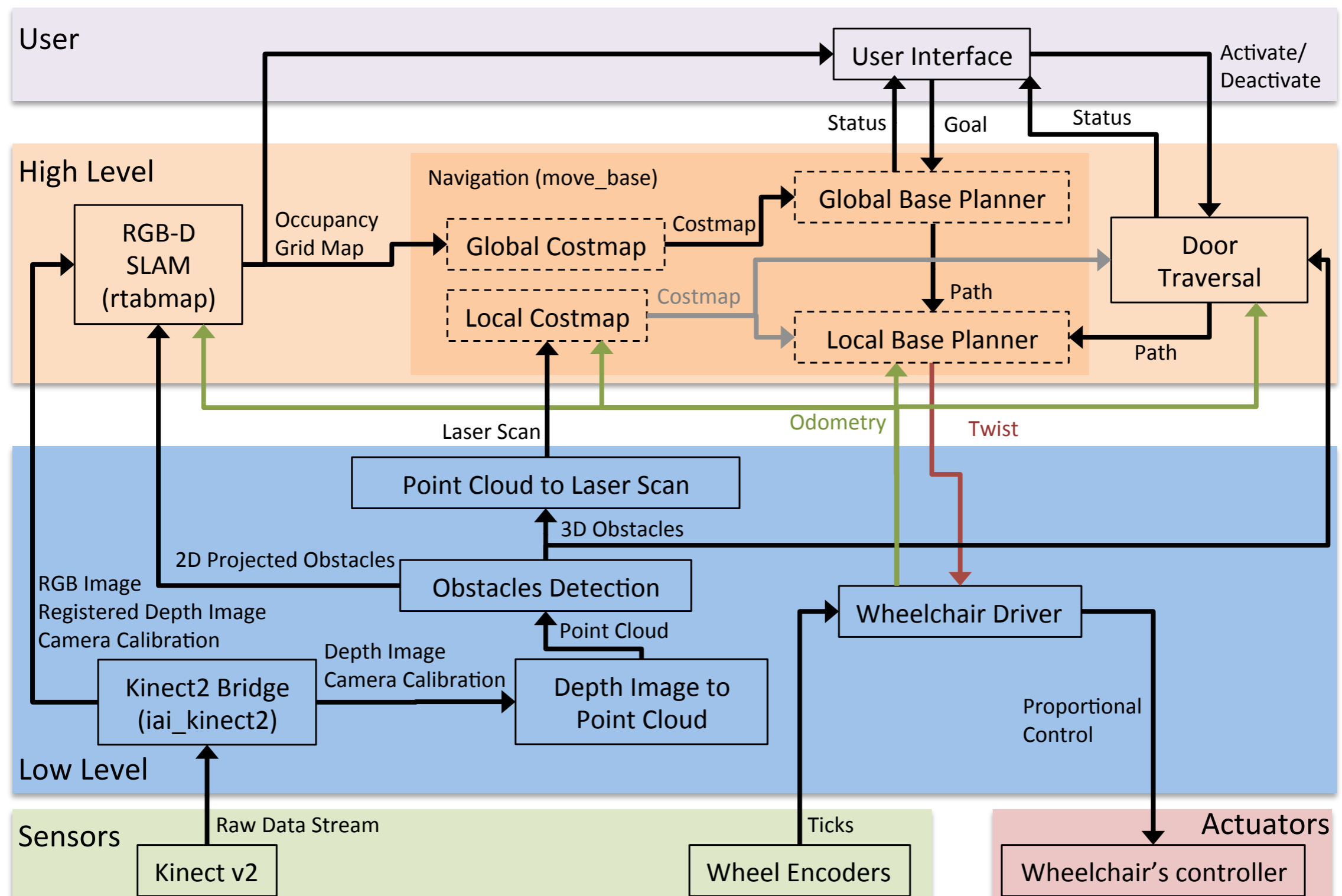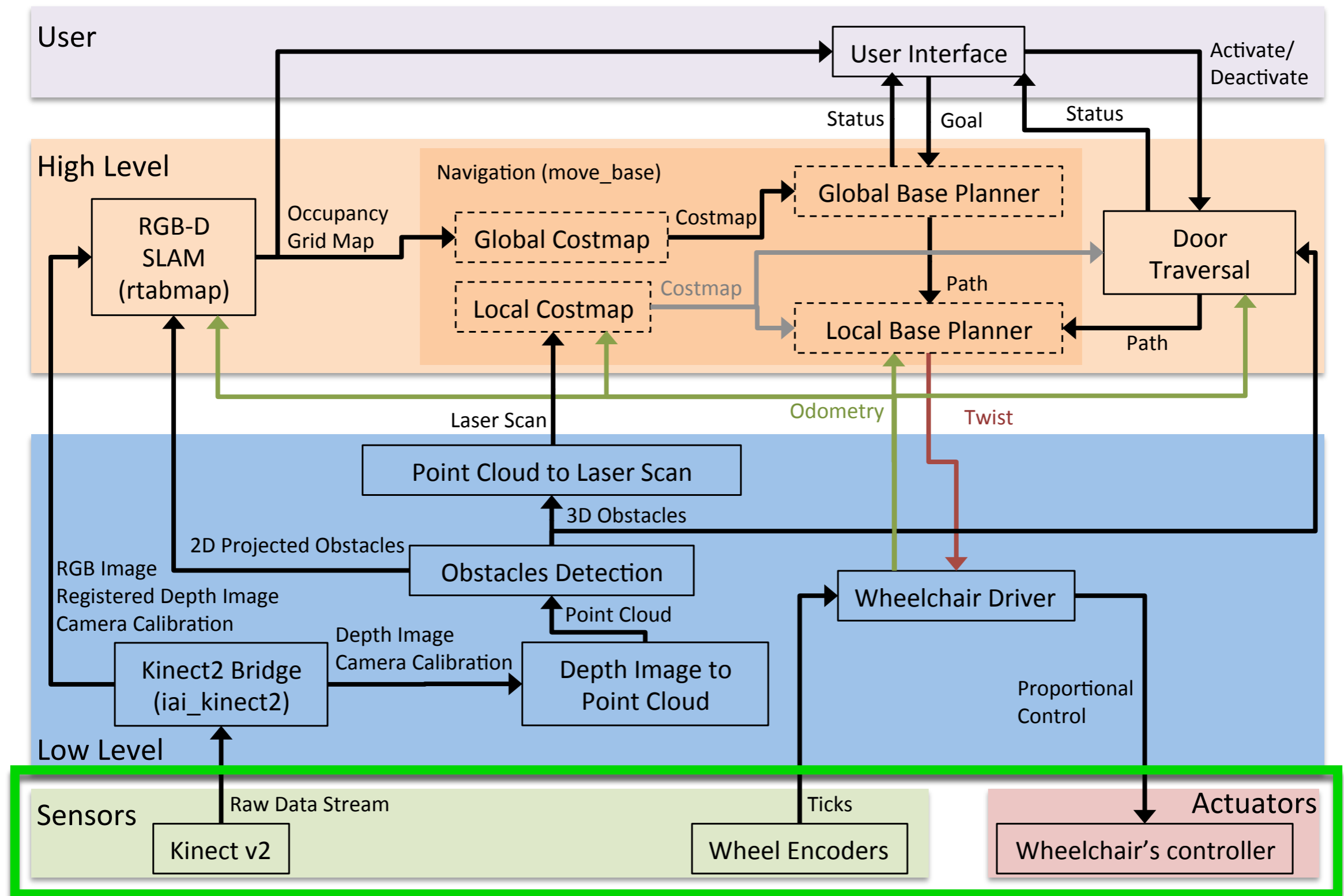
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Self-Driving System Design

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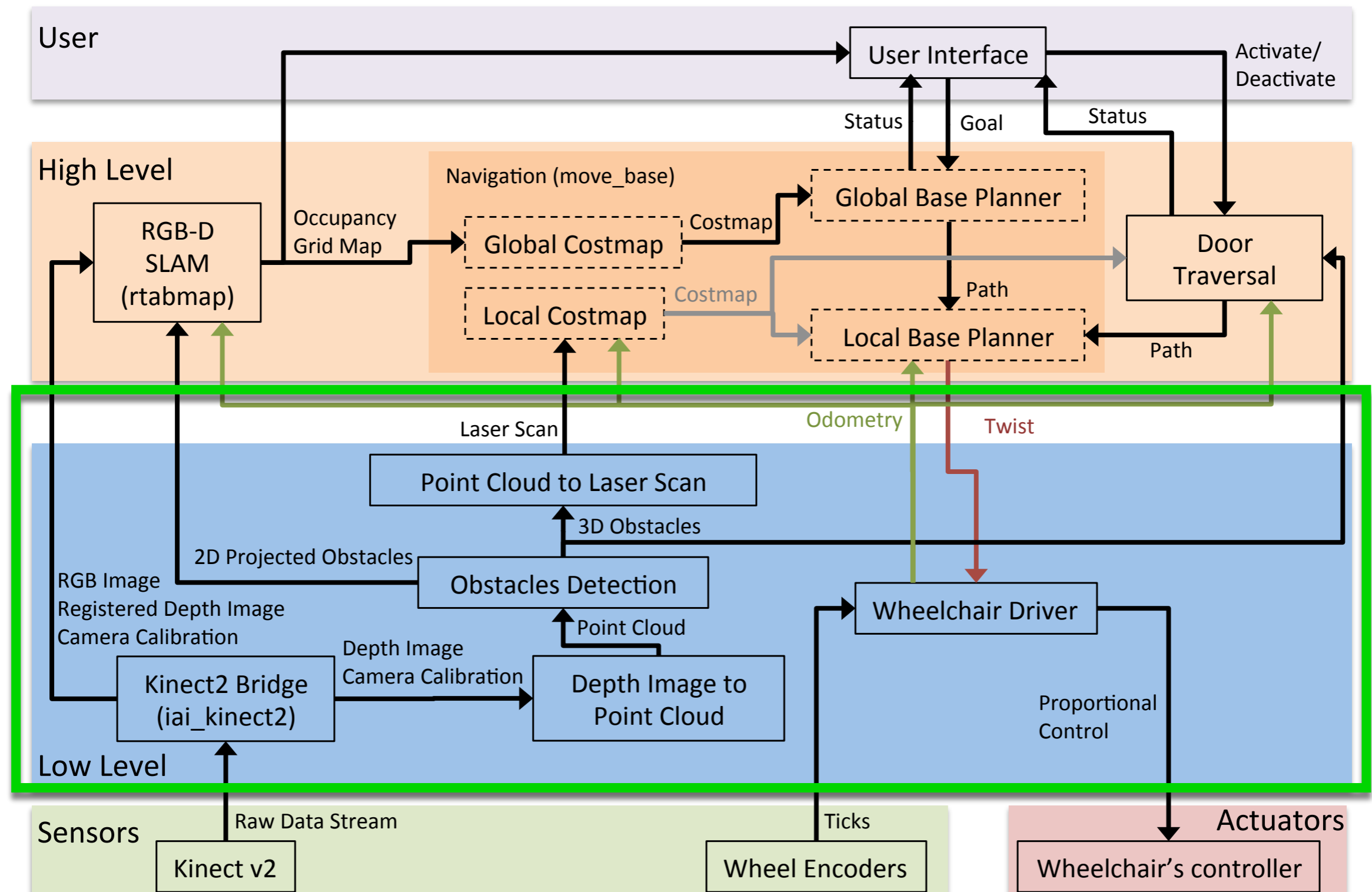
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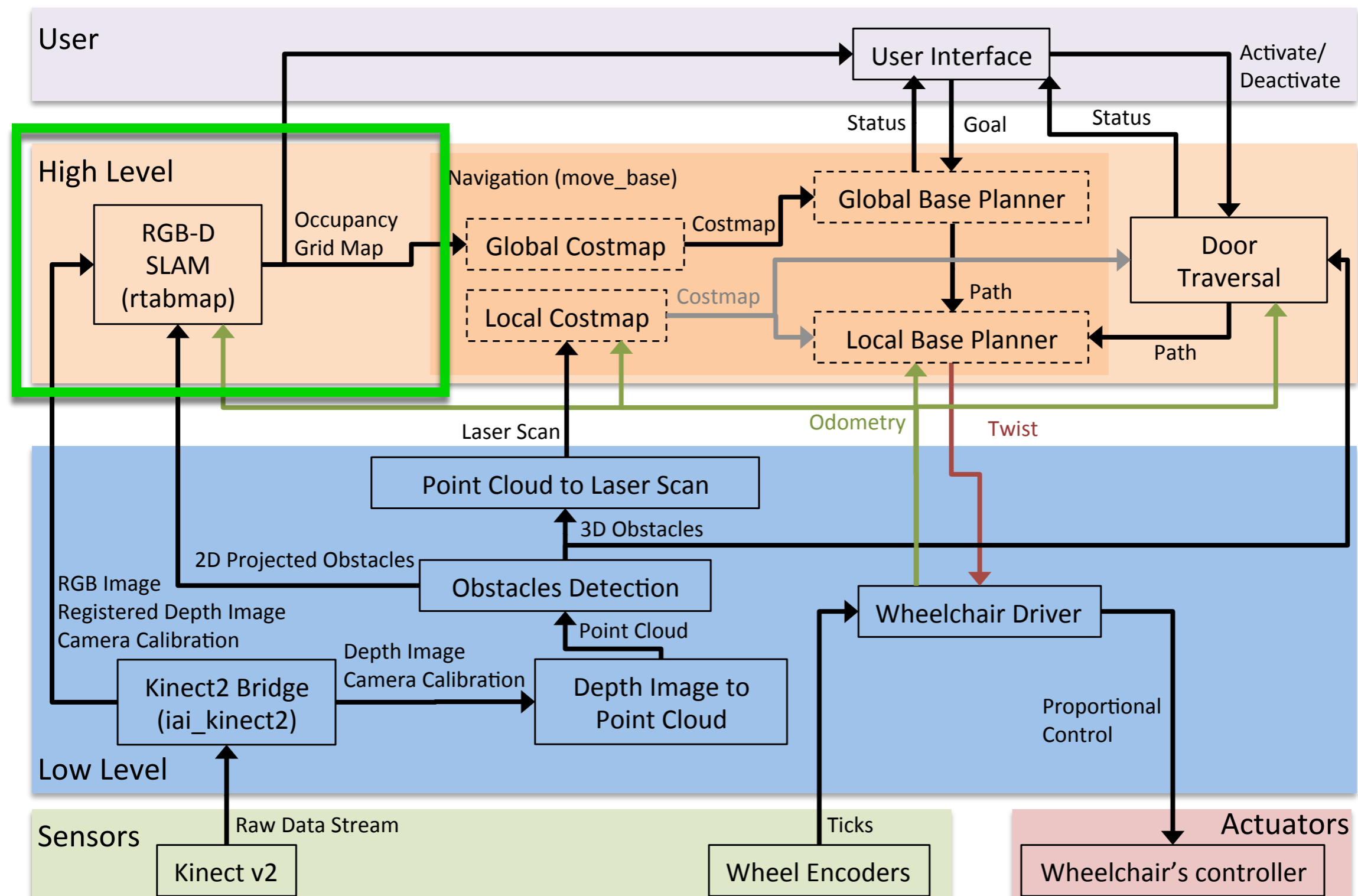
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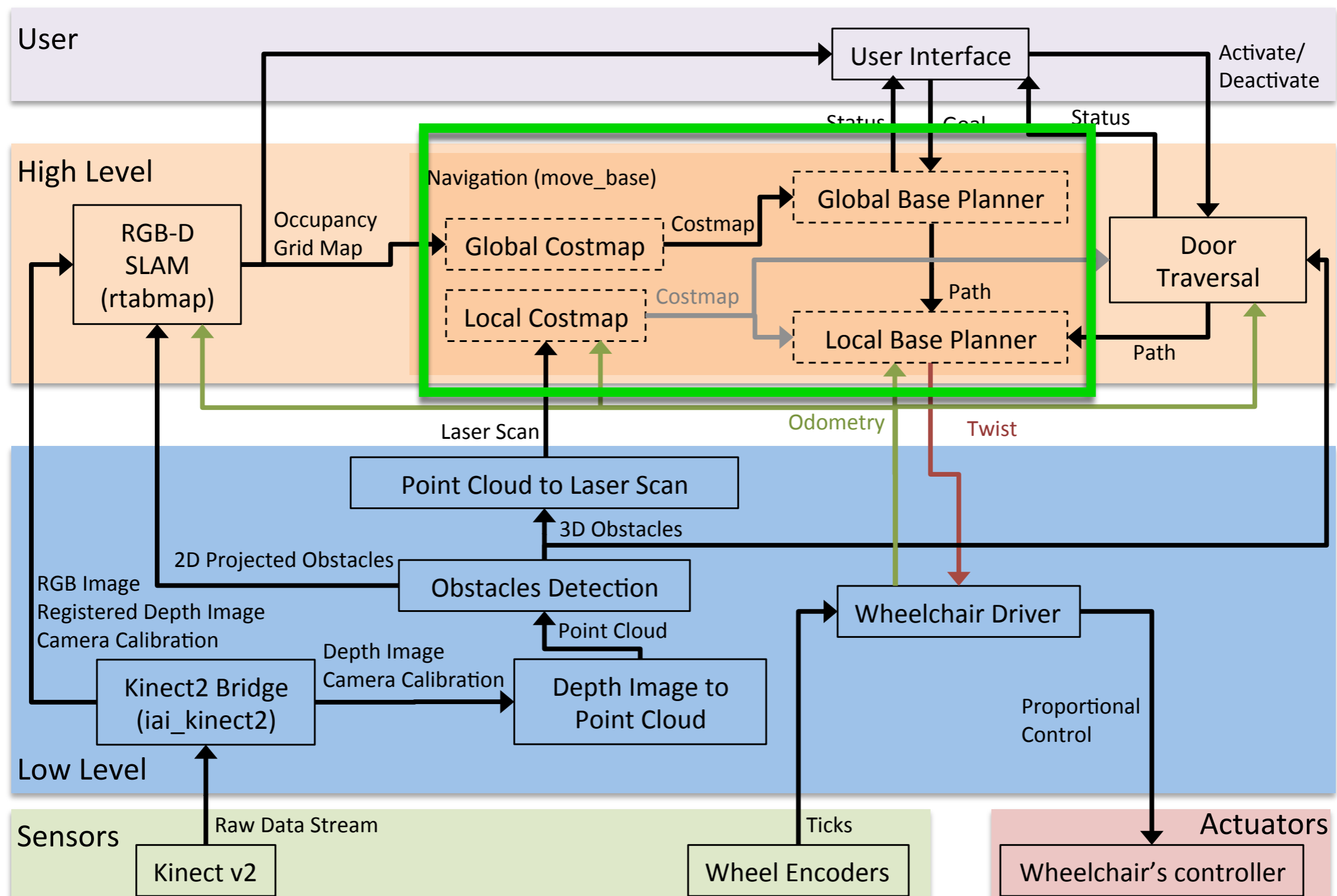
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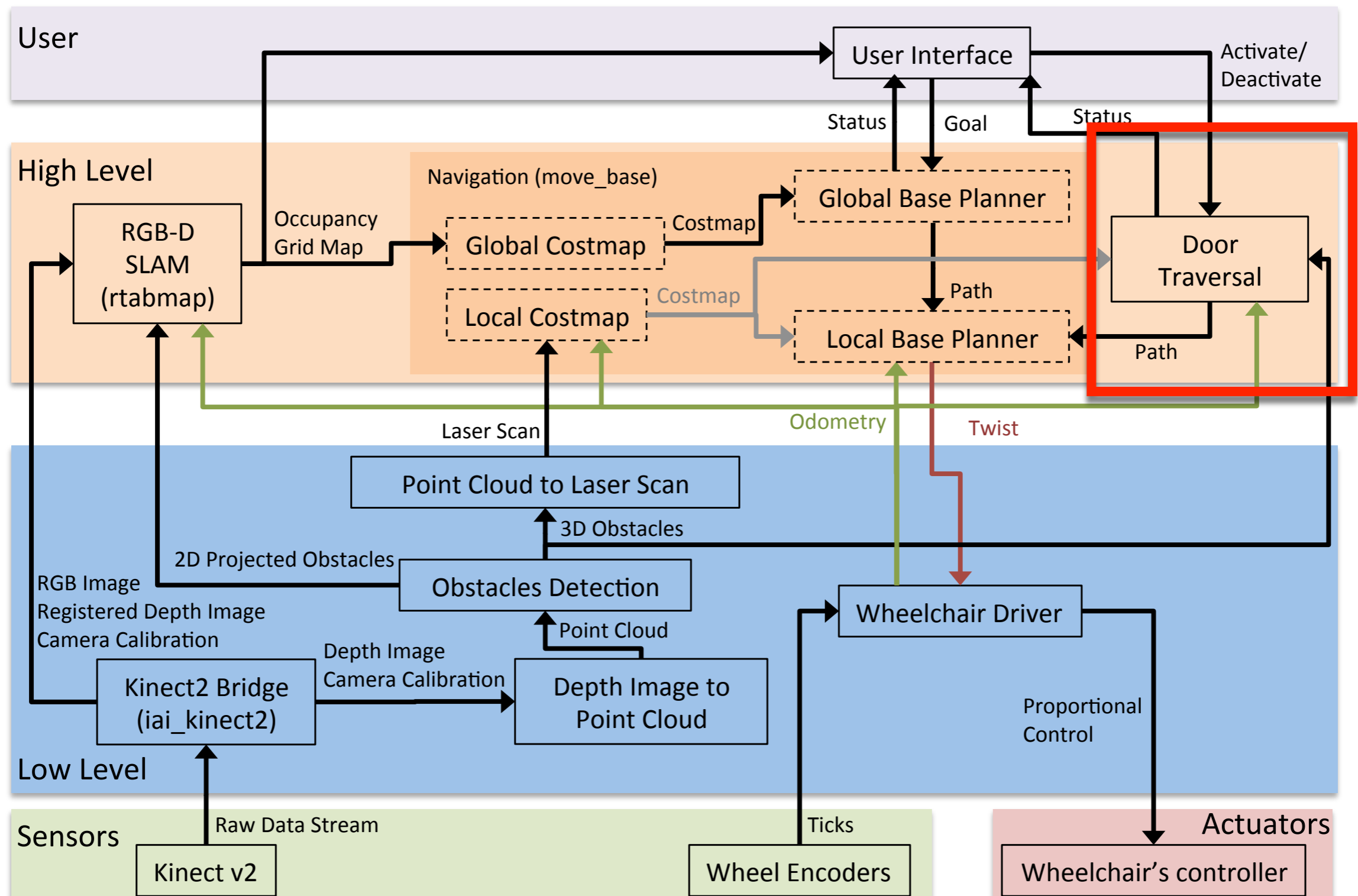
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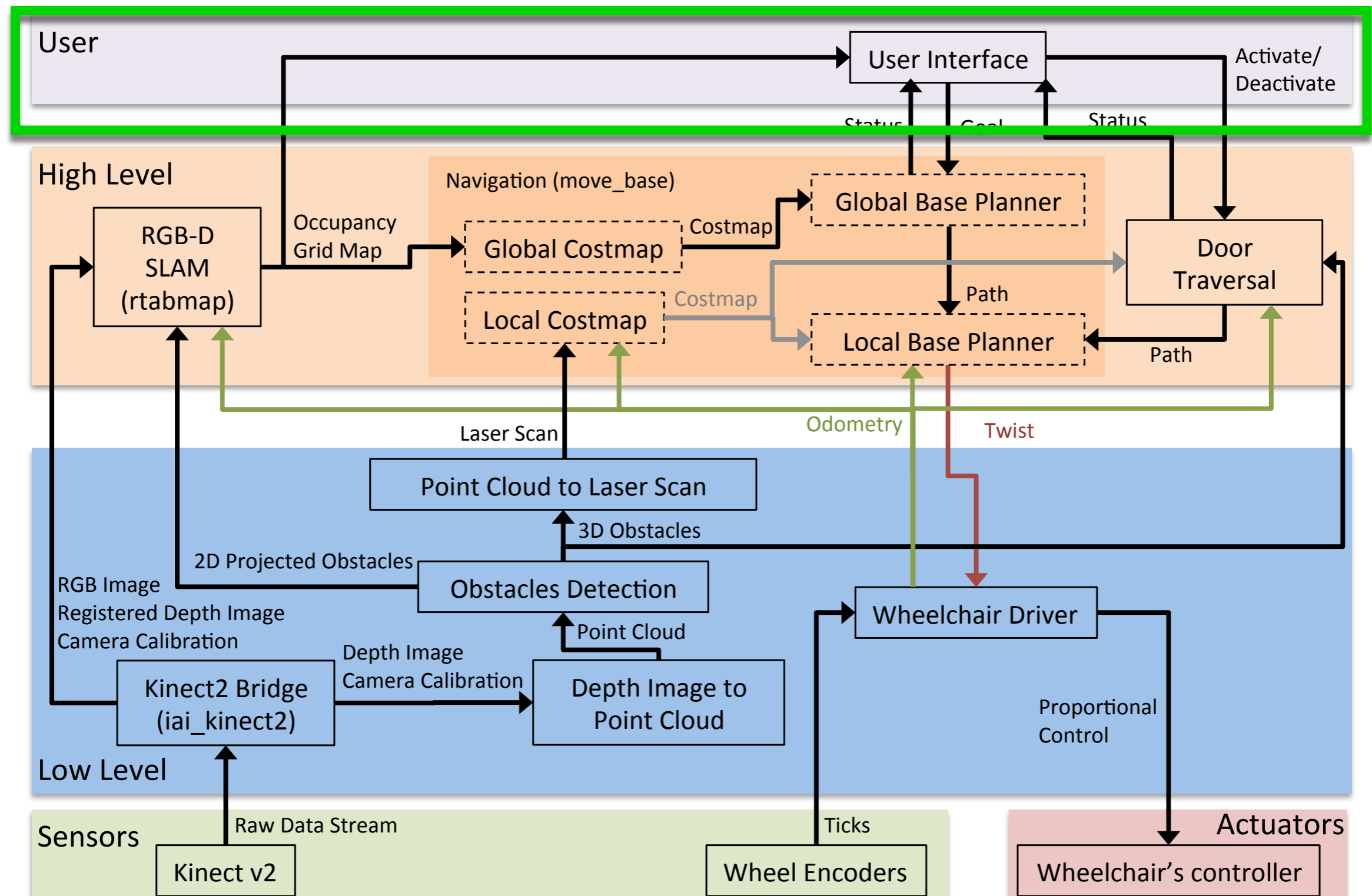
Simultaneous Localization and Mapping

- SLAM package is based on **RTAB-Map**, developed by Université de Sherbrooke (François Michaud and Mathieu Labbé)

  - Modified for use on wheelchair platform with additional code

- RTAB-Map builds a 2D occupancy grid from 3D RGB-D (by projection)

- Graph-based approach, each node stores RGB image, depth image, odometry

- Bag-of-words approach to identify loop closures and relax the graph

- Careful attention to CPU load, 1 Hz update of entire map

- Clearance information included
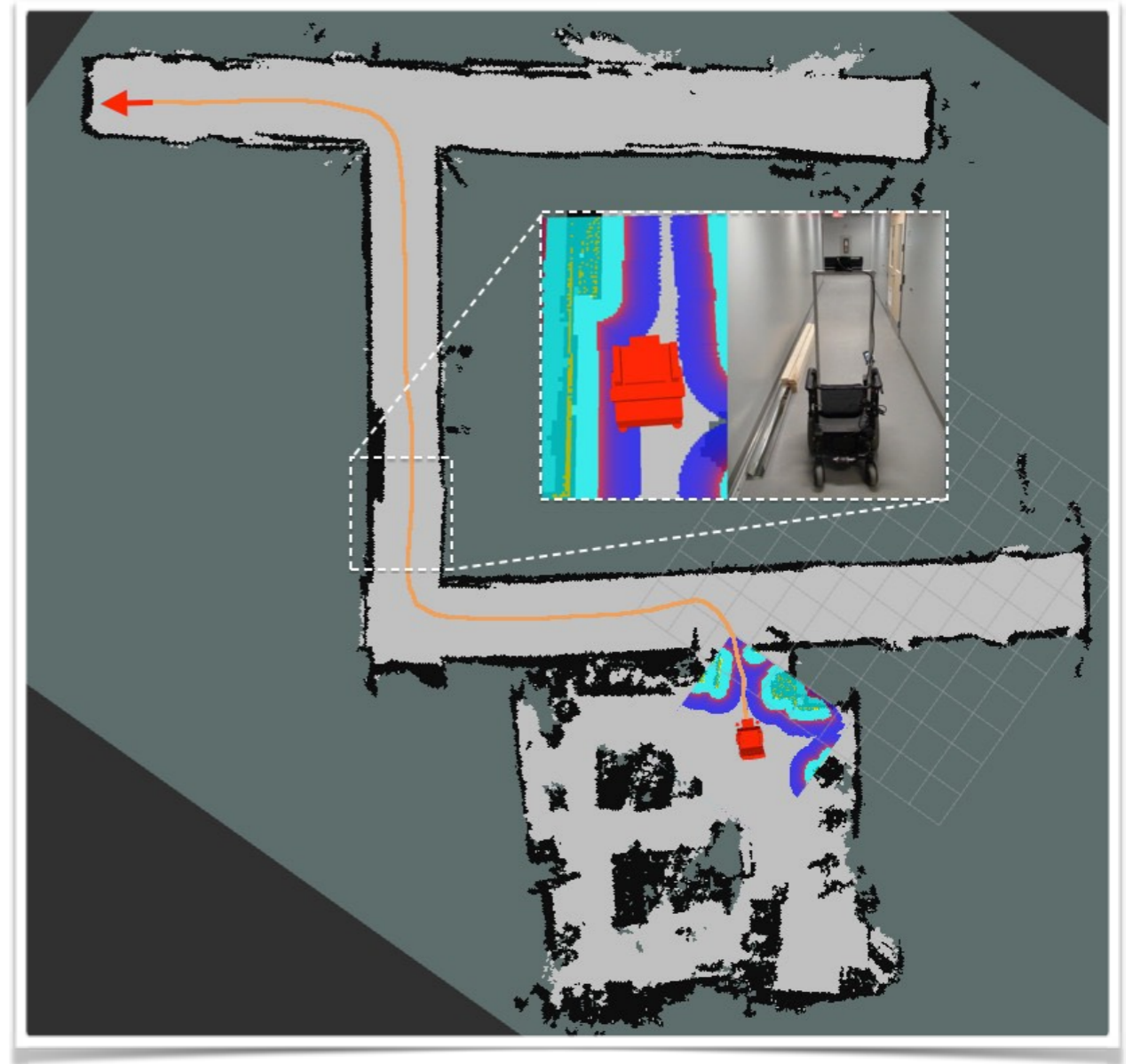
SLAM + DATMO

- Inevitably, objects that are not in the map will appear in the chair's path

- Slow-moving object (< 0.25 m/s approx.) are detected by the local base planner in the local costmap and automatically avoided whenever possible

- Fast-moving objects, which are inherently less predictable, cause the chair to stop (smoothly) and signal that it is not able to continue (could, e.g., signal caregiver)

- Cyberworks is in the process of building newer DATMO module that will enable some prediction of trajectory of moving obstacles

- Cardinal rule: **Safety First!** When in doubt, stop and ask
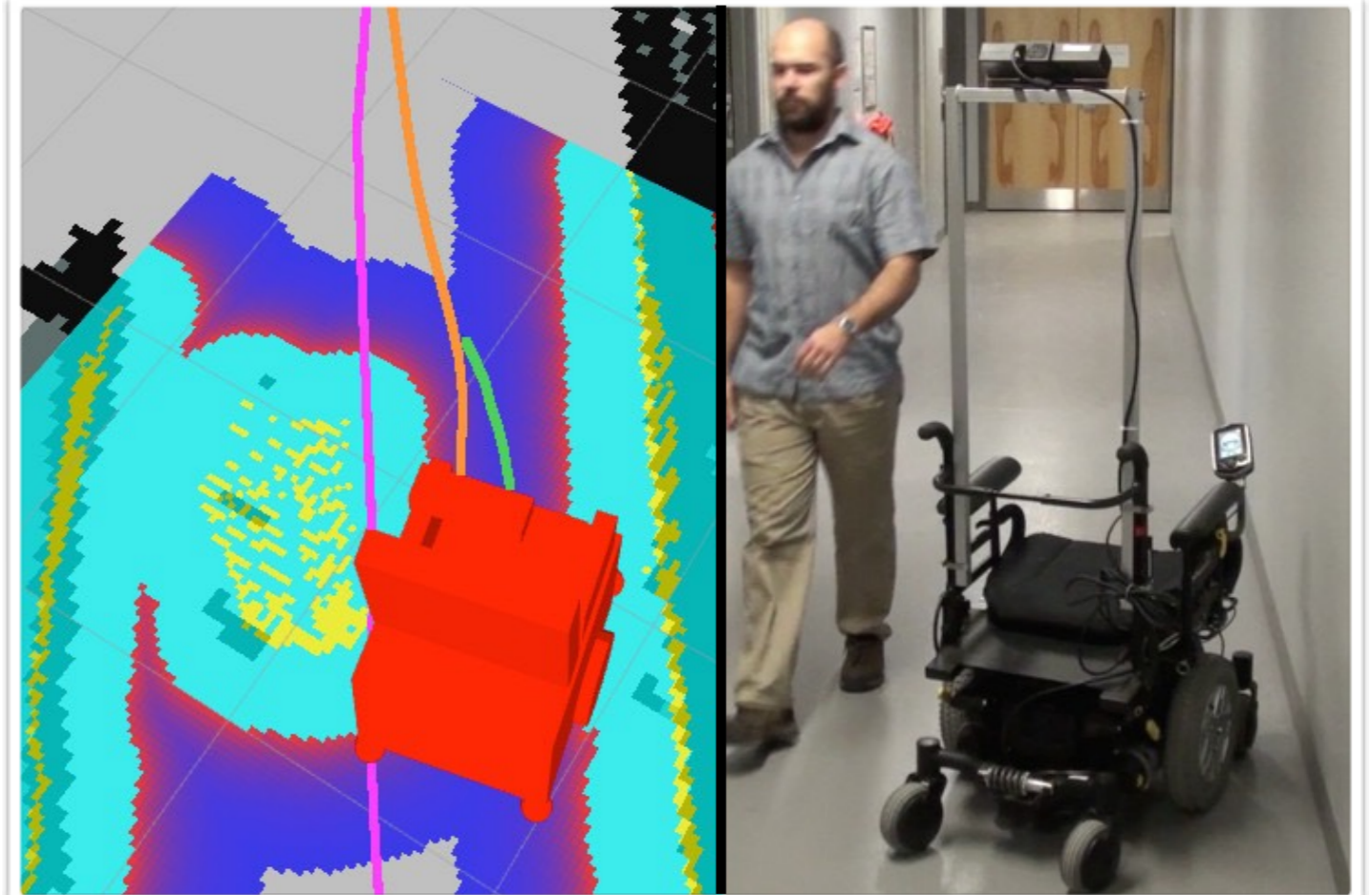
Simulation Studies: Getting to Know Your Robot

- Testing in a wide range of real environments presents range of logistical difficulties, as we all know…

  - Access to home, office, retail spaces; ability to carefully repeat trials

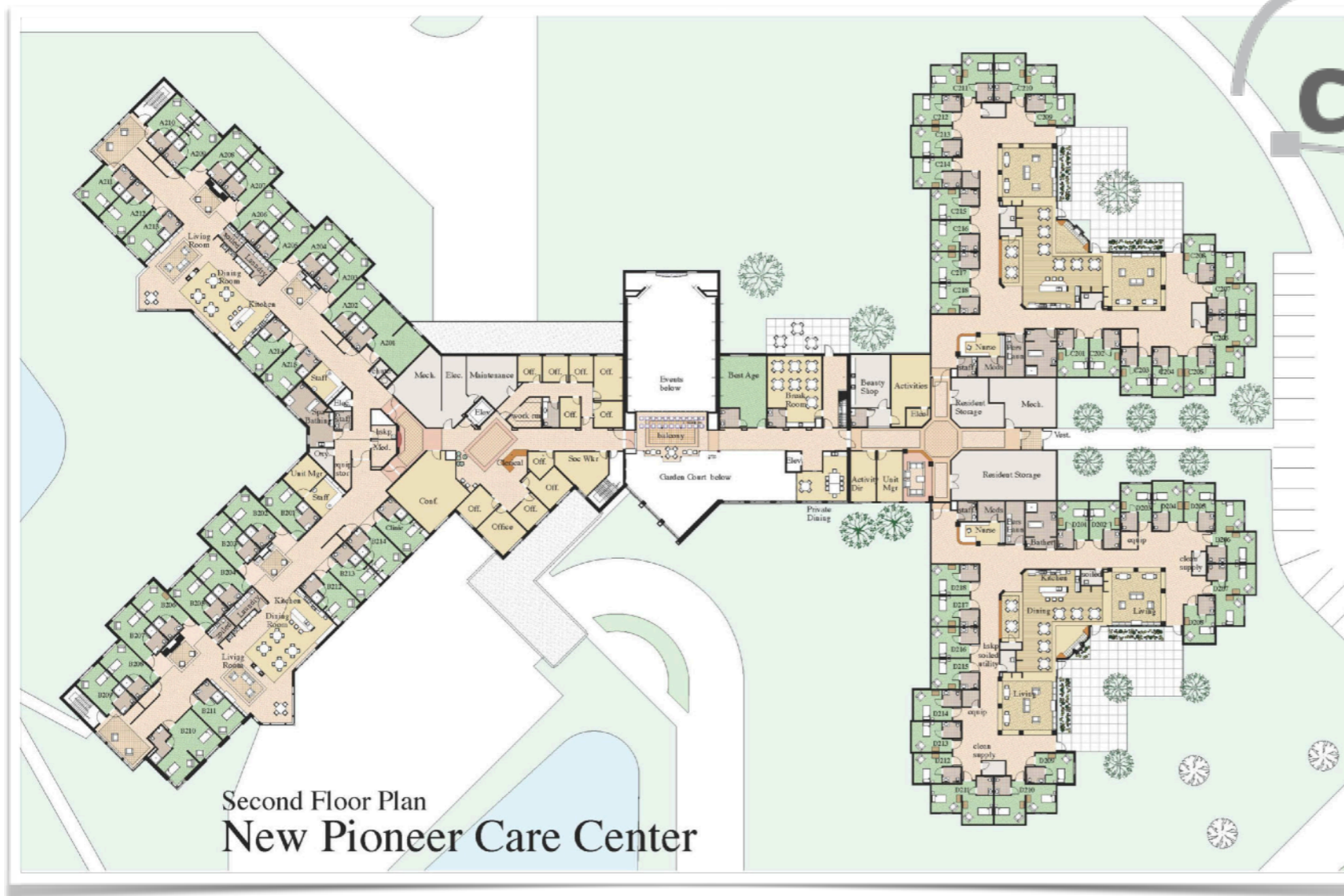- Instead, developed full Gazebo simulation with accurate dynamics
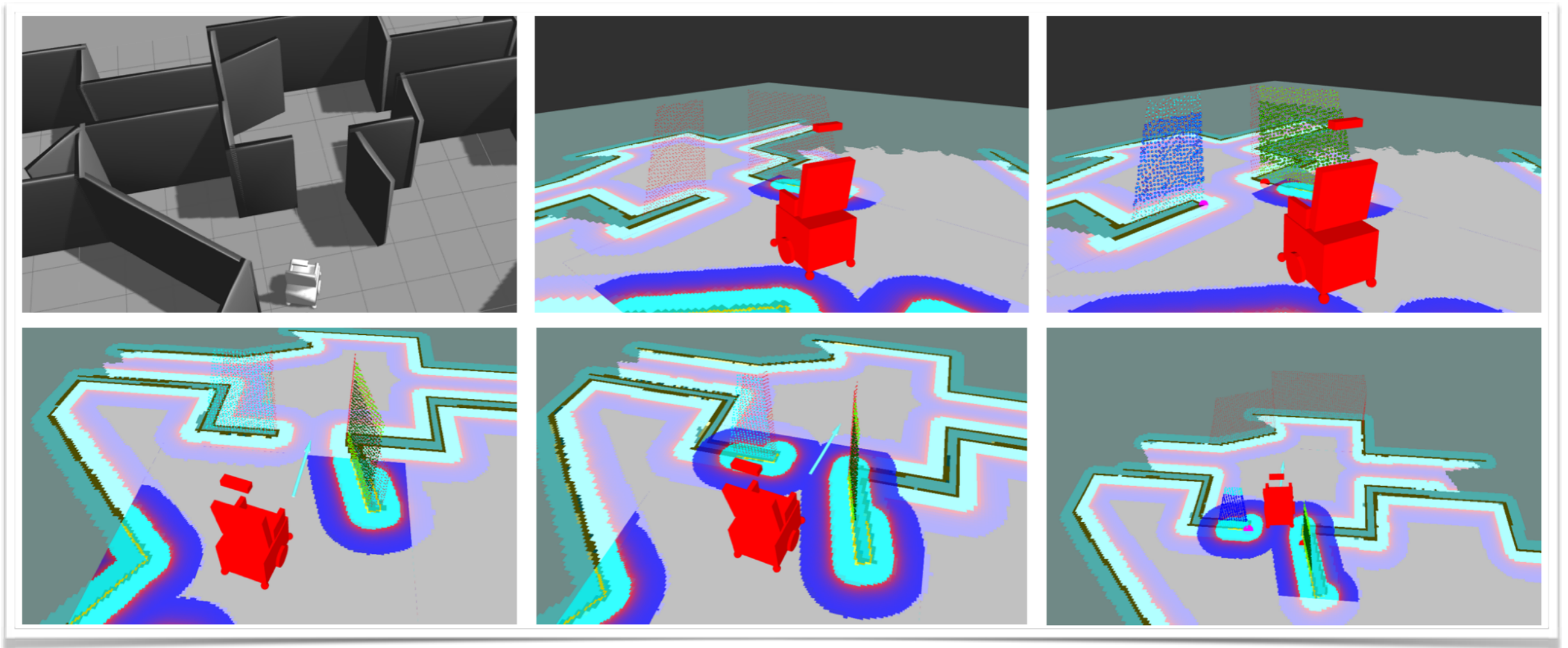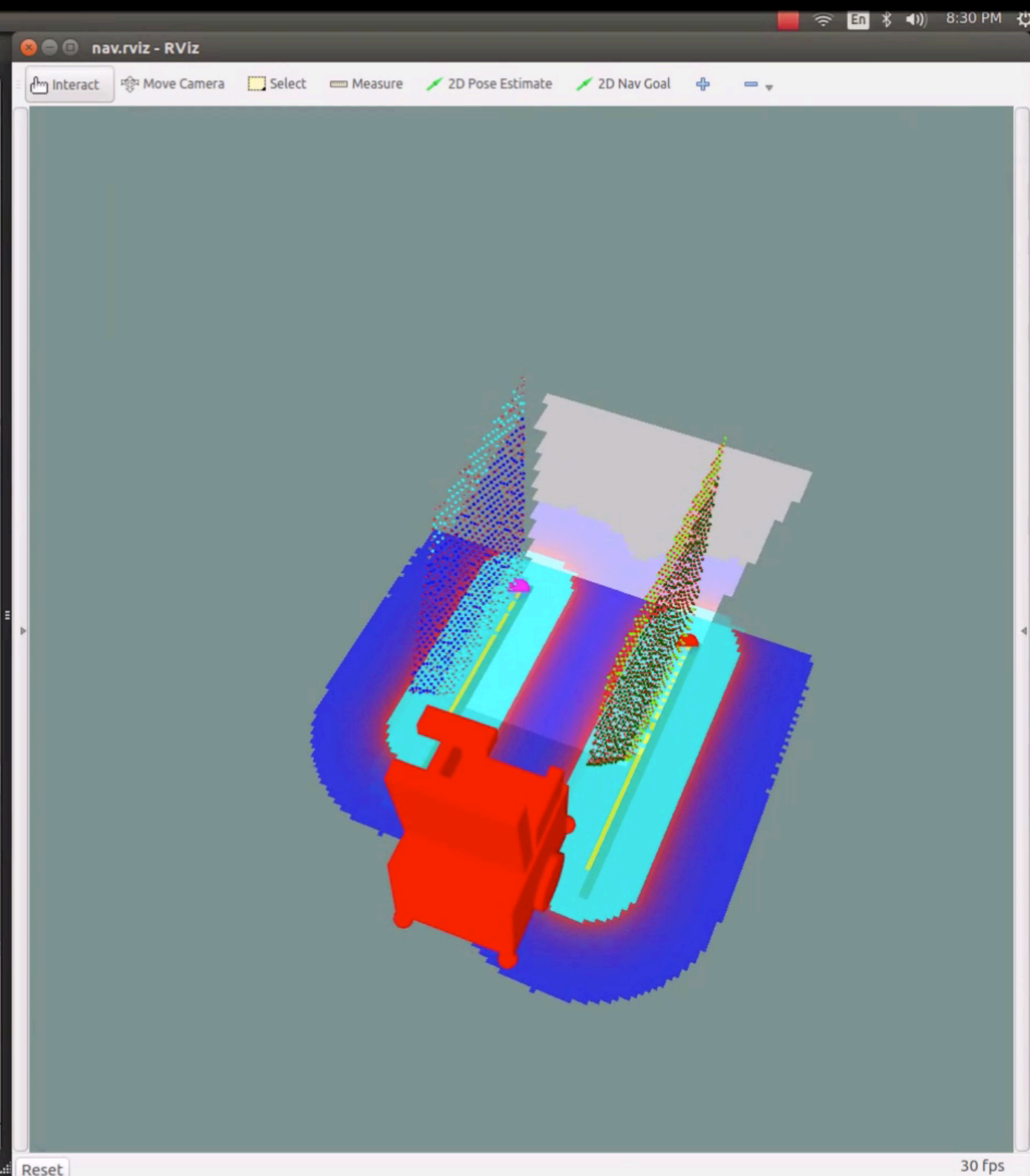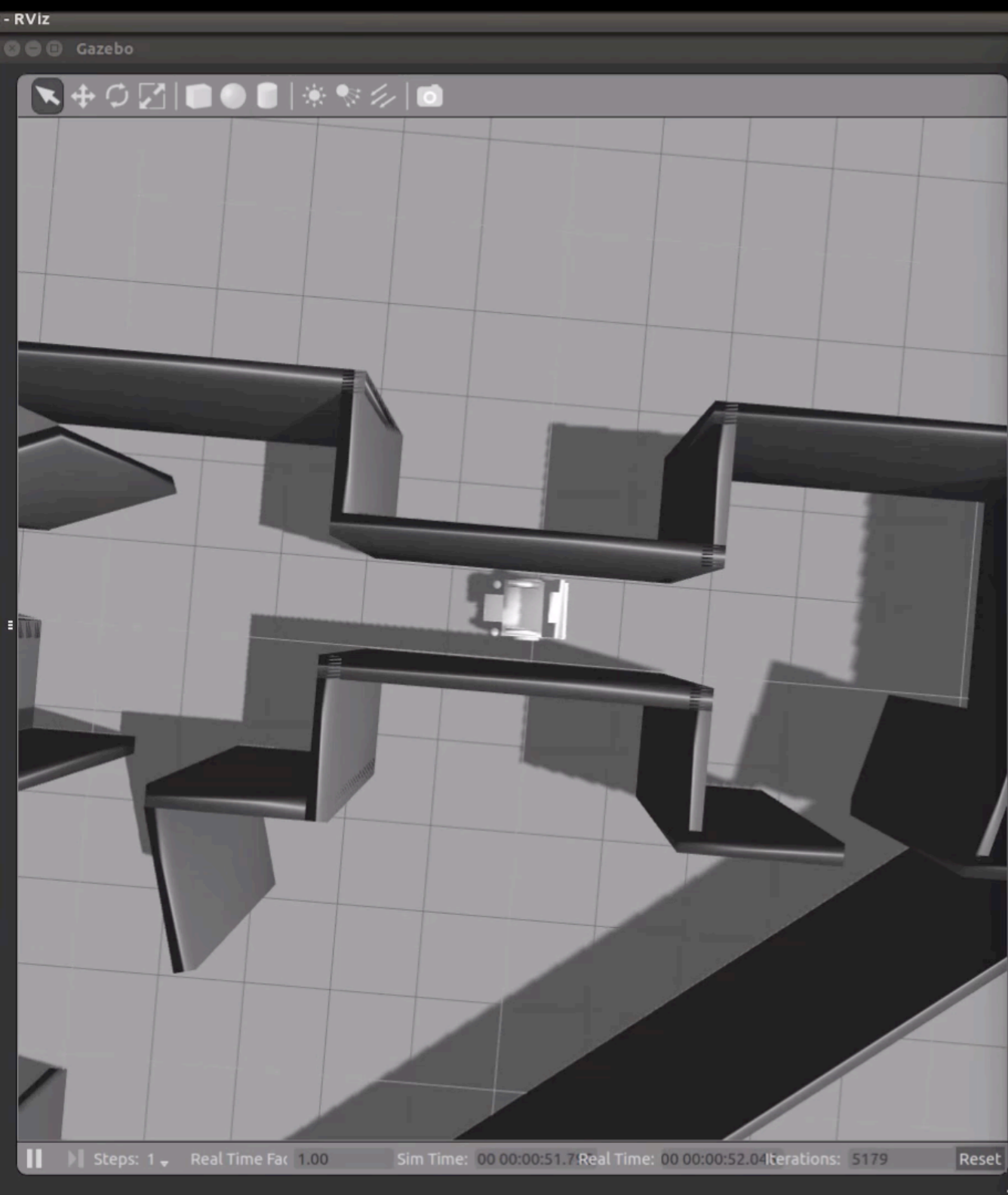
Leveraging Cloud Robotics: Shared Maps

- CloudSLAM technologies would be *ideal* for use in exactly the type of deployment environments we are considering

Second Floor Plan
New Pioneer Care Center

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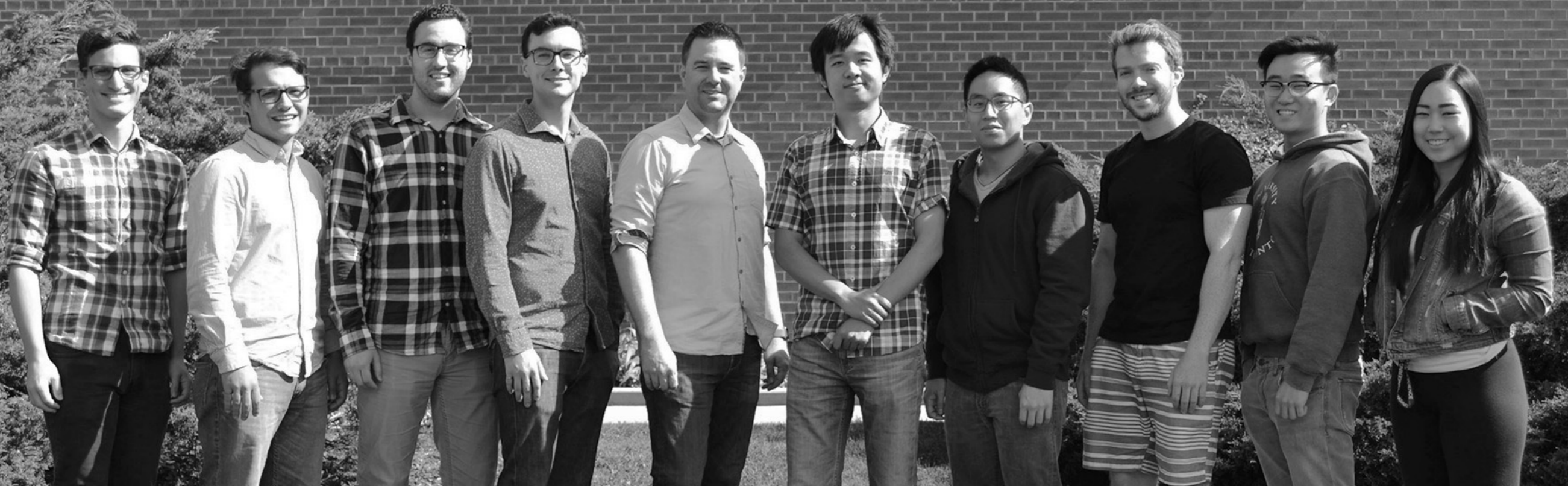**New Pioneer Care Center**

Current Development Stage

- Prototypes are built and operating well (even in environments with glass and metal, reflections)

- We have partnered with occupational therapists at U of T to proceed with evaluation and human trials

- Main challenges that remain are ethics board approval (U of T) and then moving on to full certification by Health Canada (plus US approval)

  - Relying on OT expertise here, as these processes and non-trivial and time consuming

  - In particular, regulatory approval and certification are unknowns, because this type of fully autonomous device has not been introduced before

If we can build self-driving cars, which operate in much more difficult scenarios, why can we not help this vulnerable segment of society?

http://starslab.ca/

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