Design of a Reconfigurable Multi-Sensor Testbed for Autonomous Vehicles and Ground Robots

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Introduction

Autonomous vehicle and ground robot systems are usually a composition of several sub-systems, from sensor hardware and power modules to software including control, navigation and human interface, etc.. Performing online tests on those sub-systems individually, within the entire architecture, can be troublesome, or even dangerous. Therefore, in this work, we design and implement a reconfigurable multi-sensor testbed as shown in the right figure, which presents the features of:

- **Reconfigurable on different vehicle carriers and sensors**. For disparate applications the carrier vehicle and the applied sensors can be diverse, but they may share the same algorithms for core function module. Therefore designing a testbed that can be smoothly reconfigured to different vehicles can make the test for different scenarios more feasible.
- **Self-sustaining all-in-one setup**. Required by the first feature mentioned above, the proposed testbed possesses a characteristic of self-sustaining all-in-one setup. All sensors, along with the on-board processing unit an human-interface are contained in the testbed. These efforts make the testbed able to bootstrap and connect to related carrier vehicle through only one communication bus.
- **Edge computing compatibility**. Thanks to the increasing locally deployed computation power and the advanced communication data-link, our proposed testbed performs a full compatibility with Edge Computing in Internet of Things (IoT) applications. The local onboard processing unit with 4-Gen connection, which is on the edge side of the cloud computation, has the capability of processing all the sensor data on-board, including Vision Simultaneous Localization and Mapping (V-SLAM) and semantic segmentation neuron network.

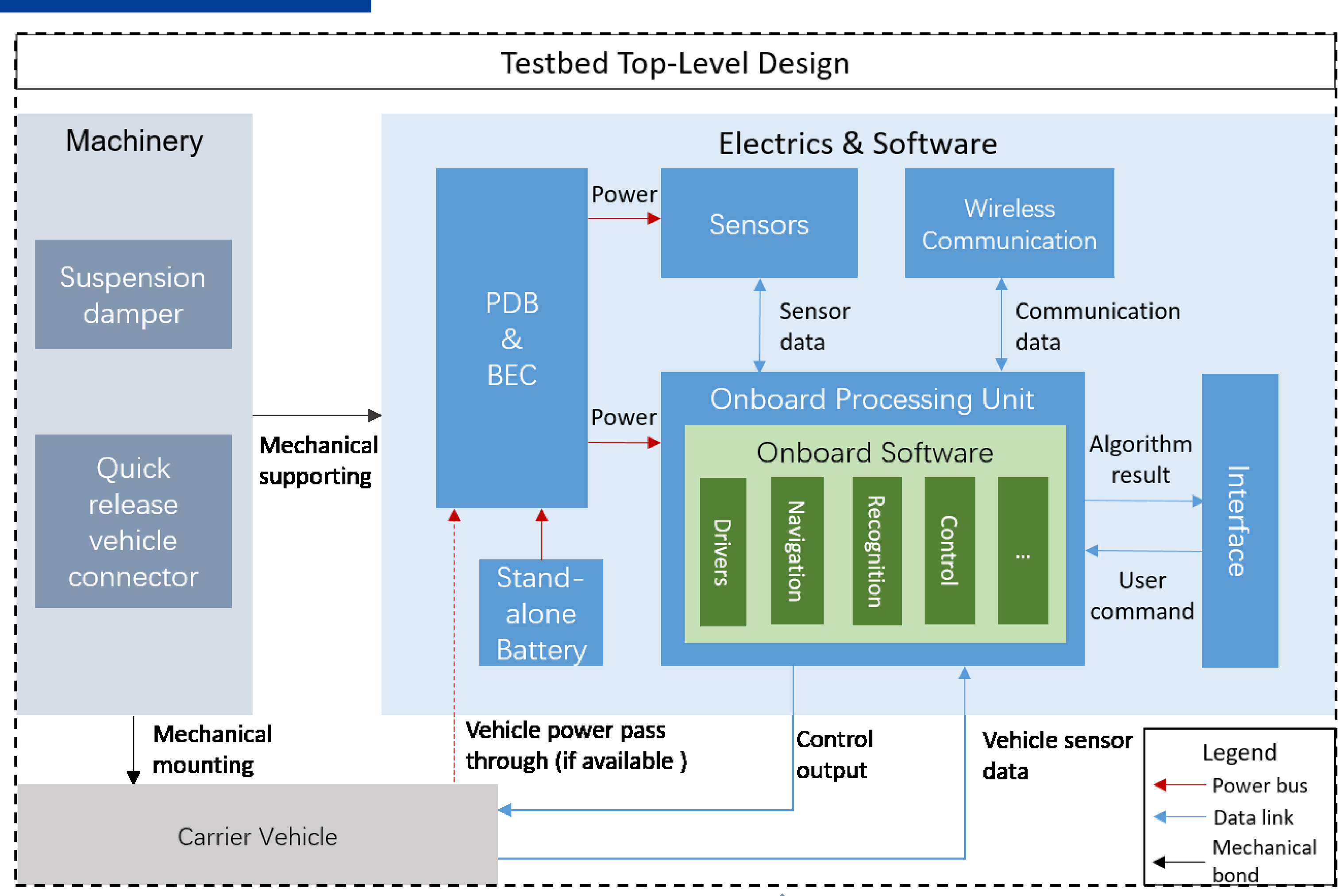
These features make the testbed a novel and ideal platform for **testing**, **verifying** and **prototyping** algorithms and applications on navigation, recognition and control under diverse scenarios.

Proposed testbed (central red box) with its different reconfigurable ground vehicles.

System Design and Architecture

Sensors and Onboard Processing Unit

- Intel® Core™ i7 processor and NVIDIA® GeForce® GTX 1070 MXM graphic module
- 1 × ZED® stereo camera
- 2 × SparkFun® 9DoF IMU
- 1 × Data Miracle® Smart-ToF™ TC-E2 Depth Camera.
- 1 × uBlox® M8P GNSS Receiver
- 1 × Velodyne® VLP-16 Lidar
- 1 × Seeed® ReSpeaker Mic Array v2.0



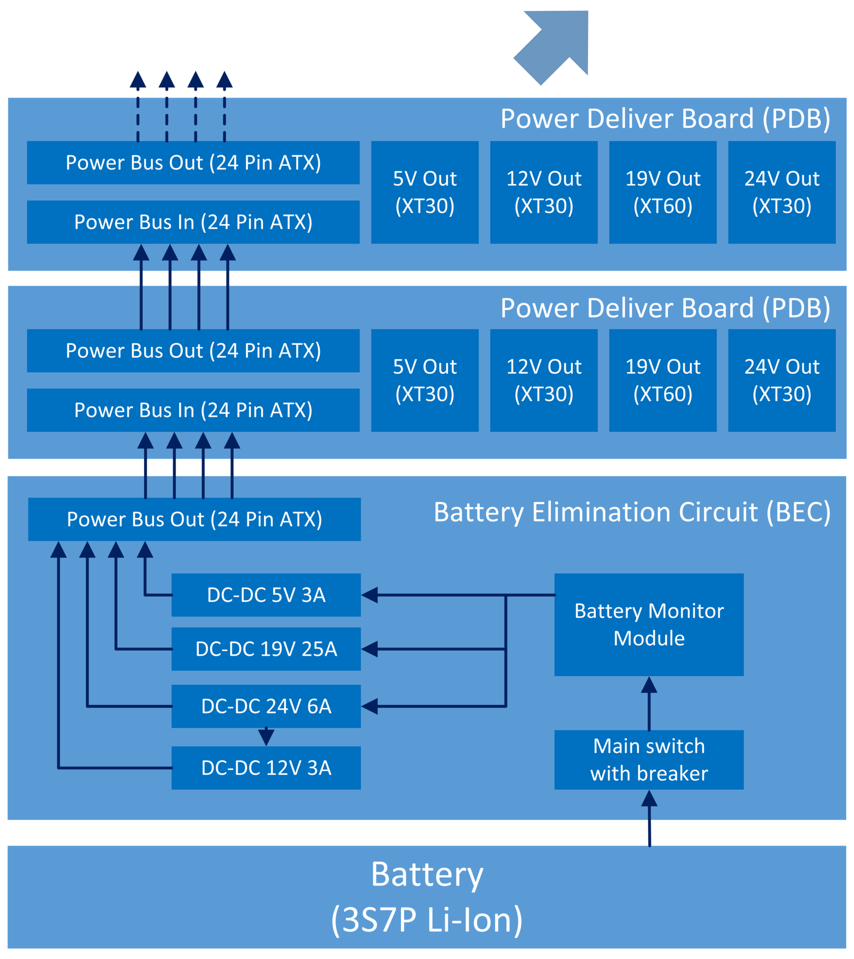
The top-level design for the proposed system is shown in the left figure. The system is composed of three major parts: mechanical structure, electronics sub-systems including power and sensors, and the onboard processing unit with its corresponding software.

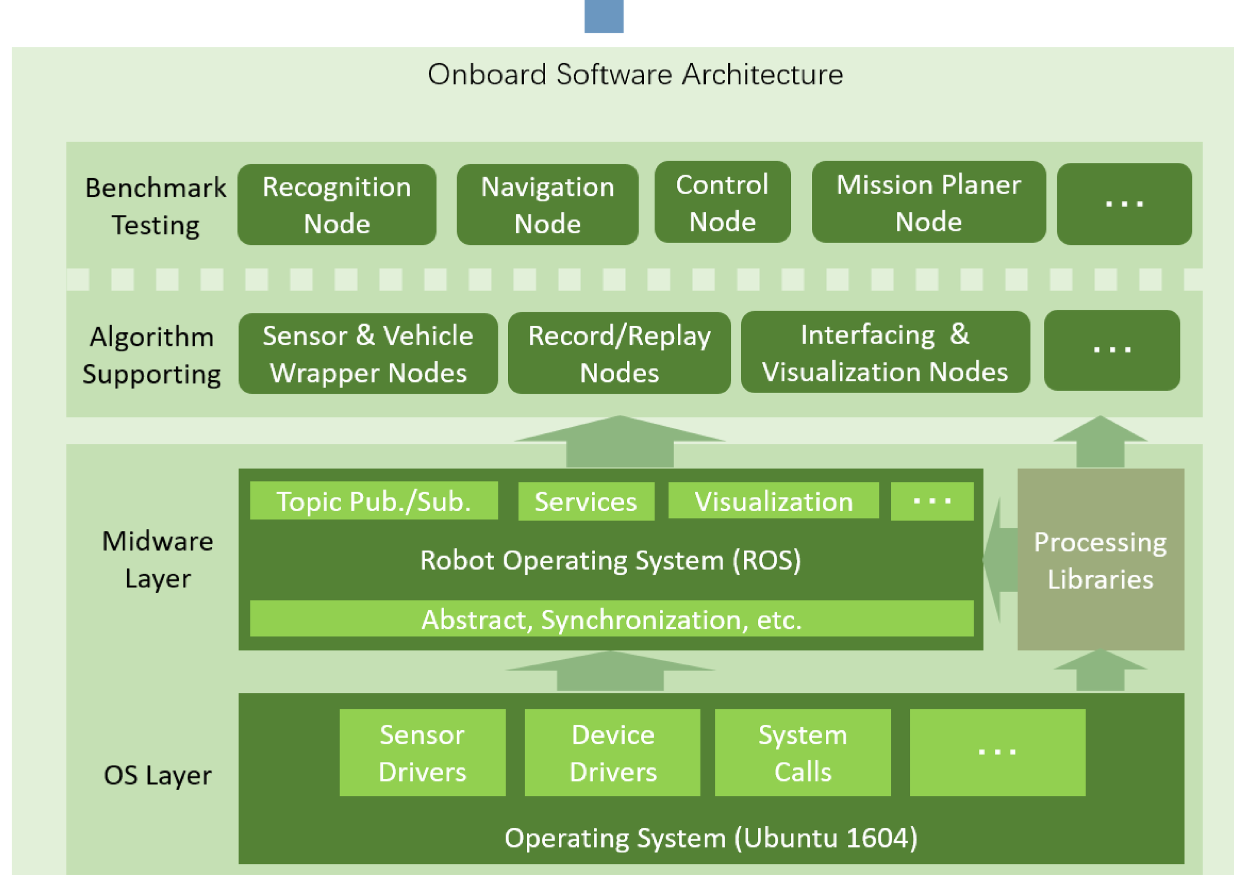
The mechanical structure of this system have three features: First, the testing unit should be conveniently transferred from vehicle to vehicle by the help of a quick release/mount mechanism. Secondly, as the testbed is designed for working with different sizes of ground vehicles, damping is provided by a suspension module. Finally, to ensure we can reconfigure sensors according to different platforms, a multi-layer structure is designed.

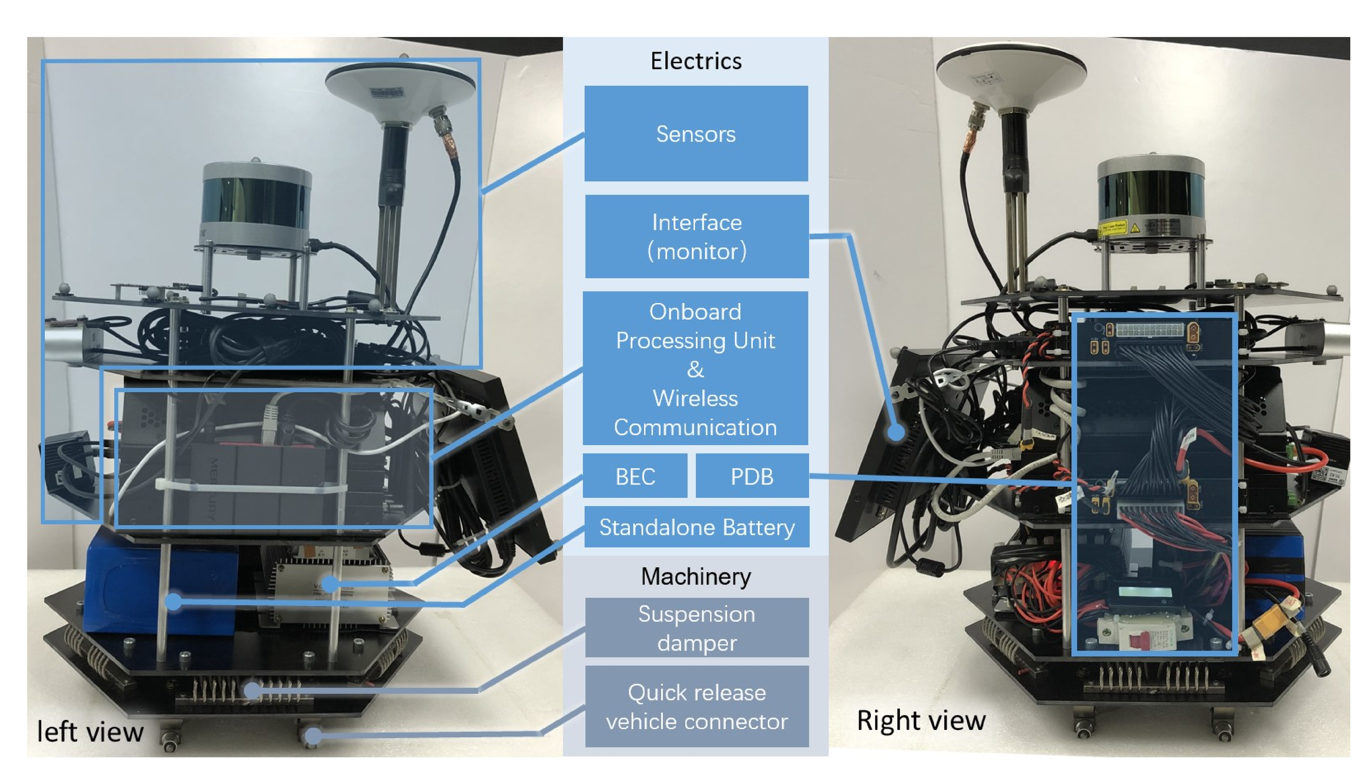
On the sensor part, our testbed currently incorporates Lidar, stereo camera, TOF depth camera, GNSS receiver, IMU and microphone array to holistically observe and understand the scene. The full suite of sensors is listed left.

The on-board software is a Robot Operating System (ROS) based software stack, including localization, navigation, mission planner etc..

To implement the proposed testbed as a self-sustaining all-in-one setup and to keep the maximum compatibility for all kinds of sensors, we design a power supply & deliver module. The entire module is divided into two parts, the Battery Elimination Circuit (BEC) and the Power Deliver Board (PDB). In BEC, we convert and assign all the needed voltages and currents to the power bus.



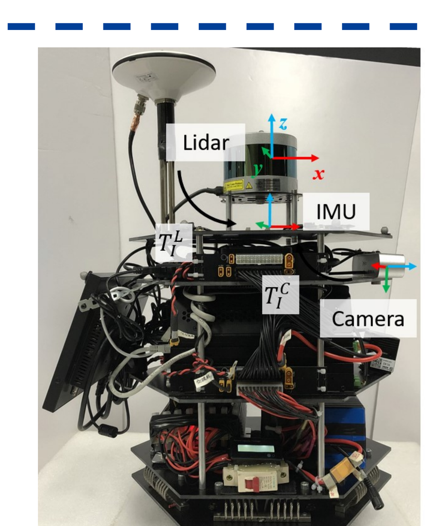




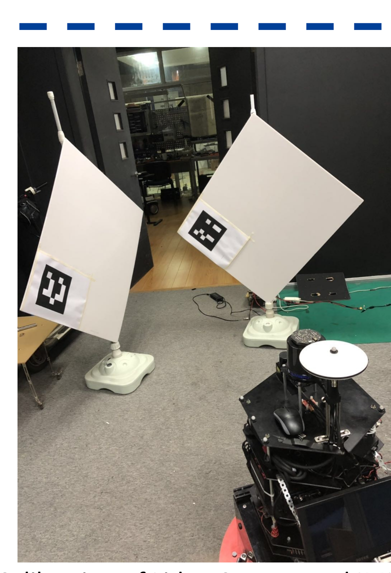
Top-level design corresponding physical modules

Calibration

As the system contains various sensors including GNSS, Lidar, IMU, stereo camera and ToF in our platform. These sensors use different coordinate systems. This leads to ambiguity when using their information directly. Therefore, calibration into an unified coordinate is required. Since the accuracy of the onboard GNSS is much lower than the other sensors, only Lidar, IMU and camera have to be calibrated precisely. The calibration is implemented using the method proposed by Ankit Dhall and the Kalibr toolset by ETHZ-ASL.



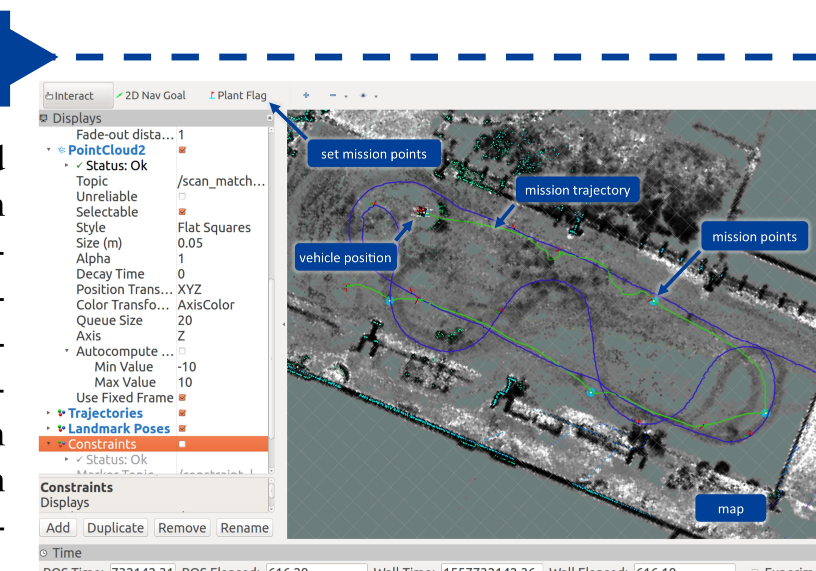
Sensor frames as well as external parameters for calibration



Calibration of Lidar, Camera and IMU with the help of ARUCO

Application and Conclusion

In this paper, we address a testbed platform equipped with a wide range of sensors and introduce the system setup as well as the onboard sensor module list. The capabilities and reconfigurability are presented by the introduction on hardware to software design. Holding the features of self-sustaining and high-performance local computation power, we believe that this testbed can yield an extraordinary effect and become an ideal testing platform for multiple research such as like object detection, ego-motion estimation and autopilot etc..



An example application of the proposed platform: autonomous data collection robot