An Open Approach to Autonomous Vehicles

IEEE MICRO, 2015

Outline

Introduction

Autonomous vehicles are becoming more prominent

Problem: no systematic organization for research purposes

Hardware Problems

- Commercial autonomous vehicles use a proprietary system interface
- No standard set of sensors

Software Problems

- No open source libraries yet exist
- Algorithm design and implementation for

Vehicles and Sensors

Introduce a set of modules, located in a plugin-in computer that can support

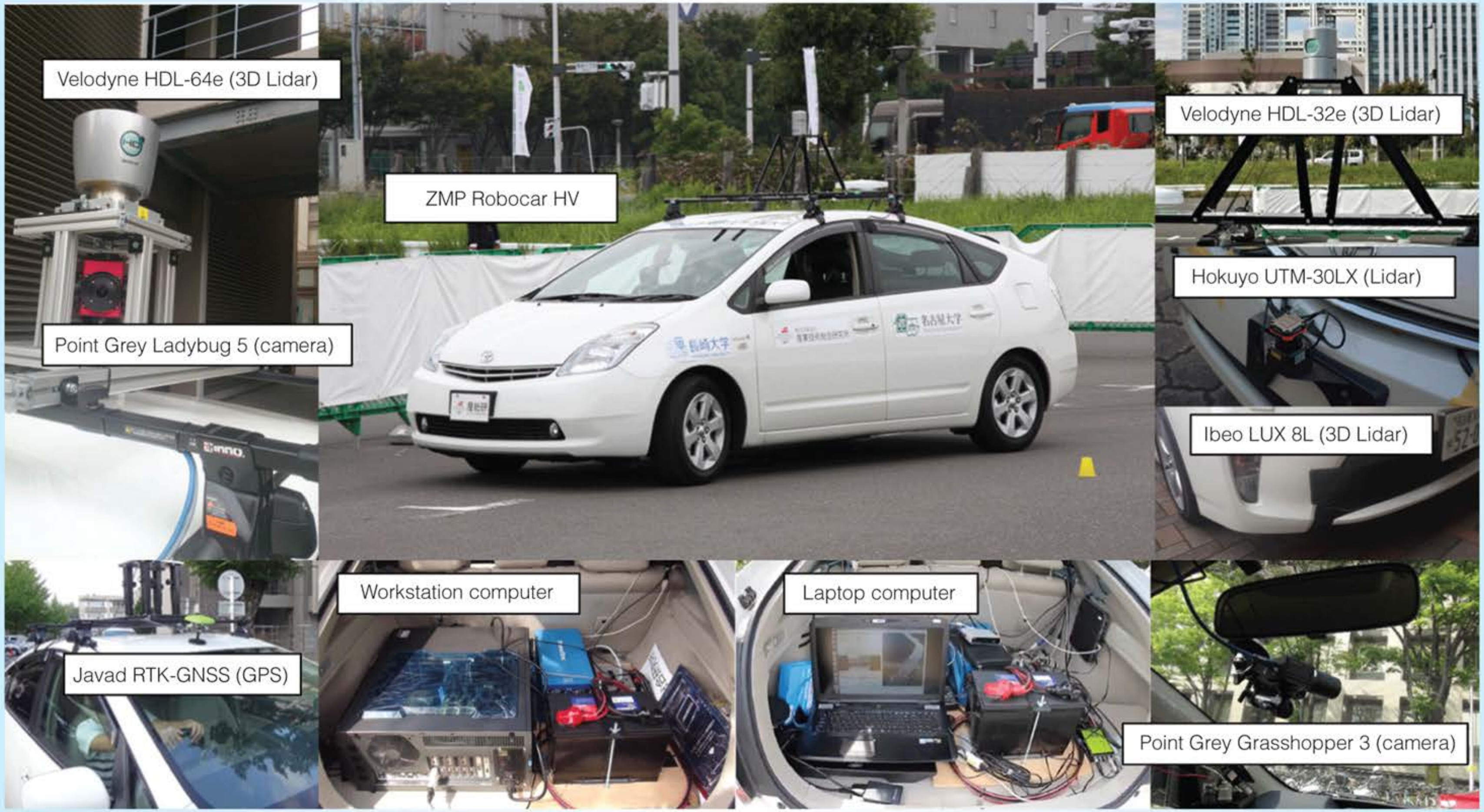
- Scene recognition
- Path planning
- Vehicle control

Connected to Controller-Area-Network (CAN) bus networks

Problem: proprietary nature of commercial vehicles does not support this

Solution: ZMP Robocar

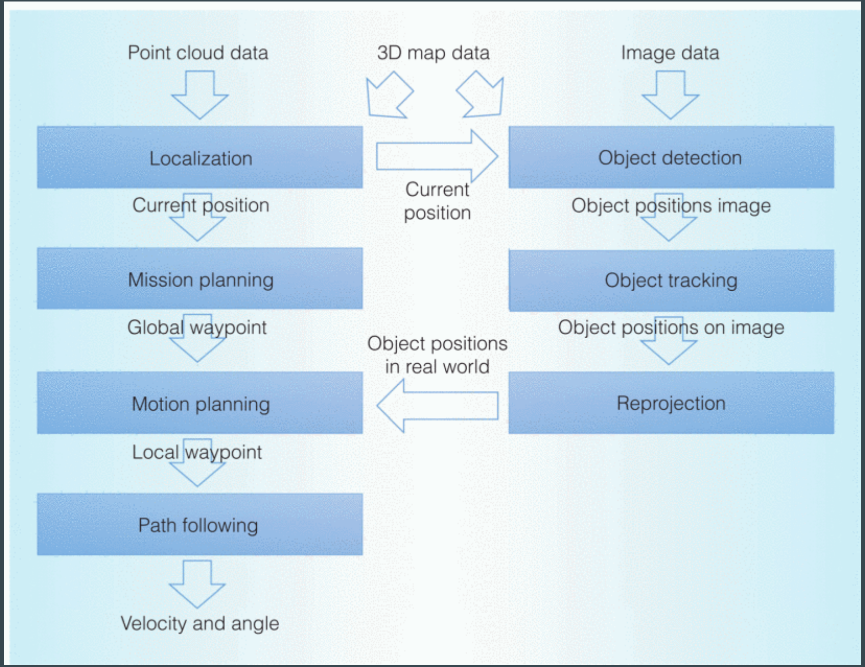
- Contains a control gateway through which commands can be sent to the car


Velodyne HDL-64e (3D Lidar)
Point Grey Ladybug 5 (camera)
ZMP Robocar HV
Velodyne HDL-32e (3D Lidar)
Hokuyo UTM-30LX (Lidar)
Ibeo LUX 8L (3D Lidar)
Javad RTK-GNSS (GPS)
Workstation computer
Laptop computer
Point Grey Grasshopper 3 (camera)

Algorithms

Autonomous driving component classification:

- Scene recognition
- Path planning
- Vehicle control

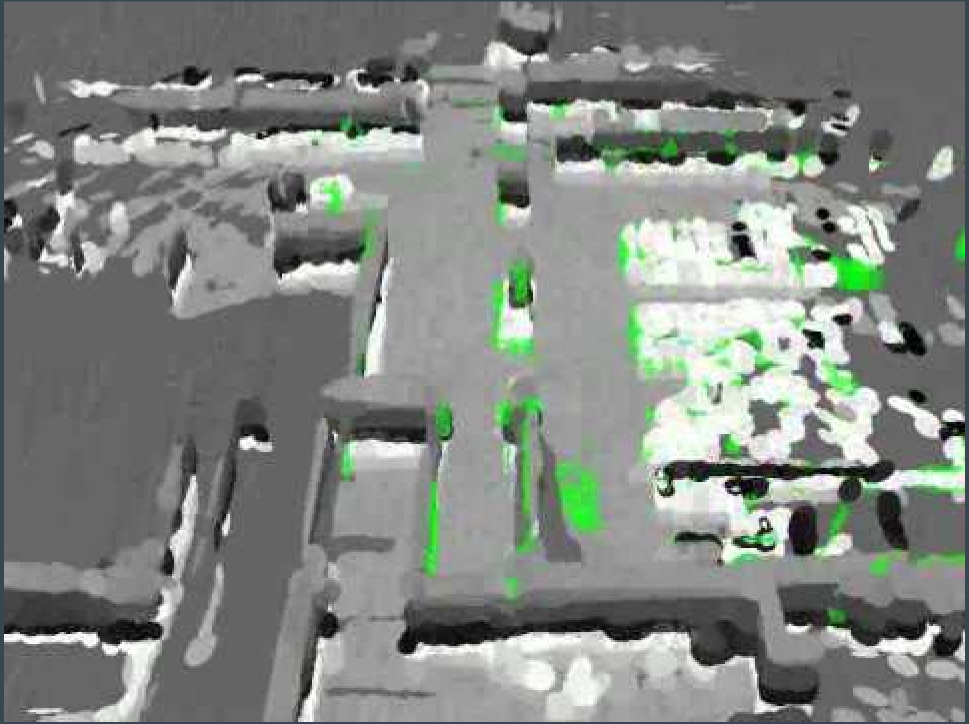


Algorithms – Scene Recognition

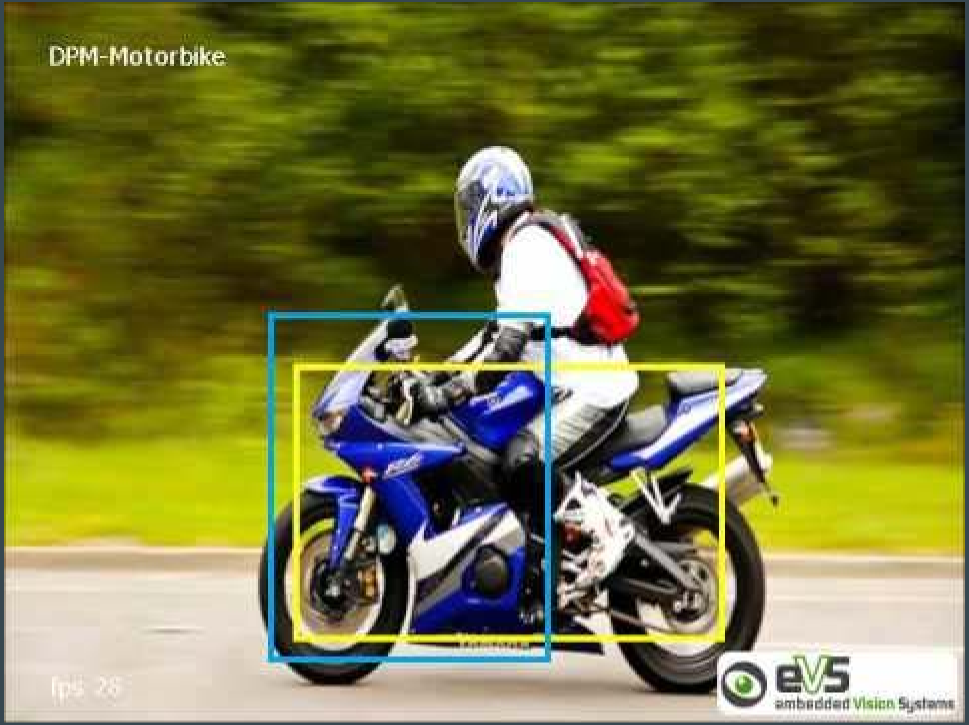
Scene Recognition requires algorithms for:

- Localization
  - Difficult in urban areas
  - Use the Normal Distributions Transform (NDT) algorithm
  - Performs scan matching over 3D point-cloud data and 3D Map data
  - Can perform at the order of centimeters
  - Chose NDT algorithms because their computation cost does not suffer from map size
- Object detection
  - Primary focus is moving objects, but also traffic lights and signs

NDT algorithm



DPM Algorithm



Algorithms – Scene Recognition (continued)

Scene Recognition requires algorithms for:

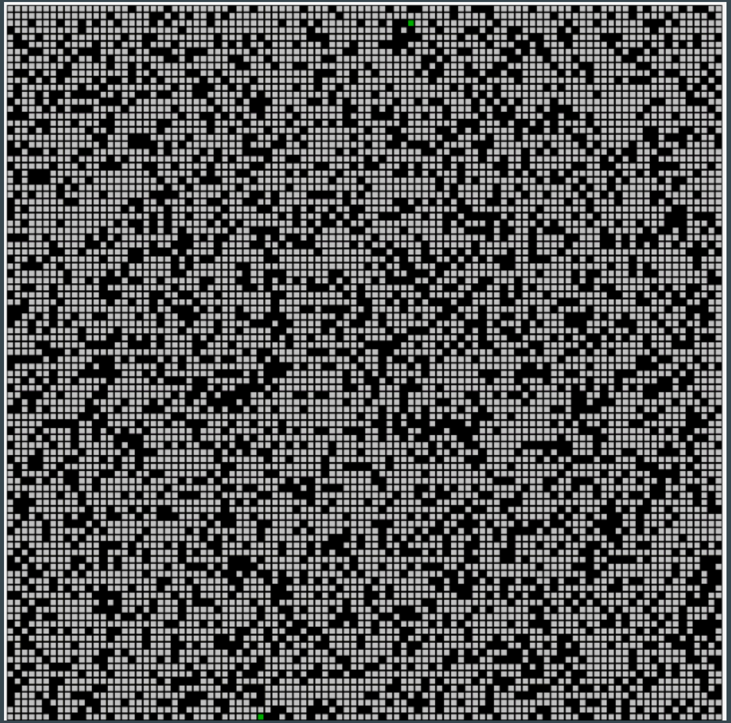
- Object detection
  - Sensor Fusion
    - Uses data from the 3D Lidar sensor to detect objects by Euclidean clustering
    - Goal: to determine distances to objects
    - Distance is used to track objects classified by the image processing
- Object tracking
  - Since object detection is run on every image frame, we can associate its results
    - Across multiple frames to predict trajectories

Algorithms – Path Planning

Path Planning requires algorithms for:

- Mission planning
  - Uses a rule-based mechanism to autonomously assign path trajectory
    - e.g., lane change, passing, merging
  - Once the path is assigned, the local motion planner is launched
  - Rule: car stays in right lane until either:
    - Passing another car
    - Turning at an intersection
- Motion planning: corresponds to driving behavior

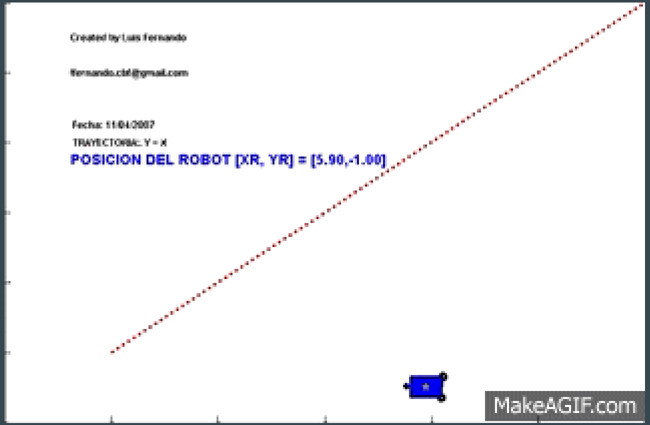
A* Algorithm



Algorithms – Vehicle Control

- Autonomous vehicle follows path generated by motion planner
- Use Pure Pursuit algorithm for the path-following problem
  - Break down path into several waypoints
  - Every cycle, search for the closest waypoint in the direction you’re heading
  - Set the velocity and angle of the next motion
  - Update waypoint accordingly until goal is finally reached

Pure Pursuit Algorithm



Software stack

Open source, publicly available framework: Autoware

Vehicle completely operated by Autoware

Components:

- Robot Operating System
- Point-Cloud Library
- OpenCV
- CUDA
- Android
  - [illegible]

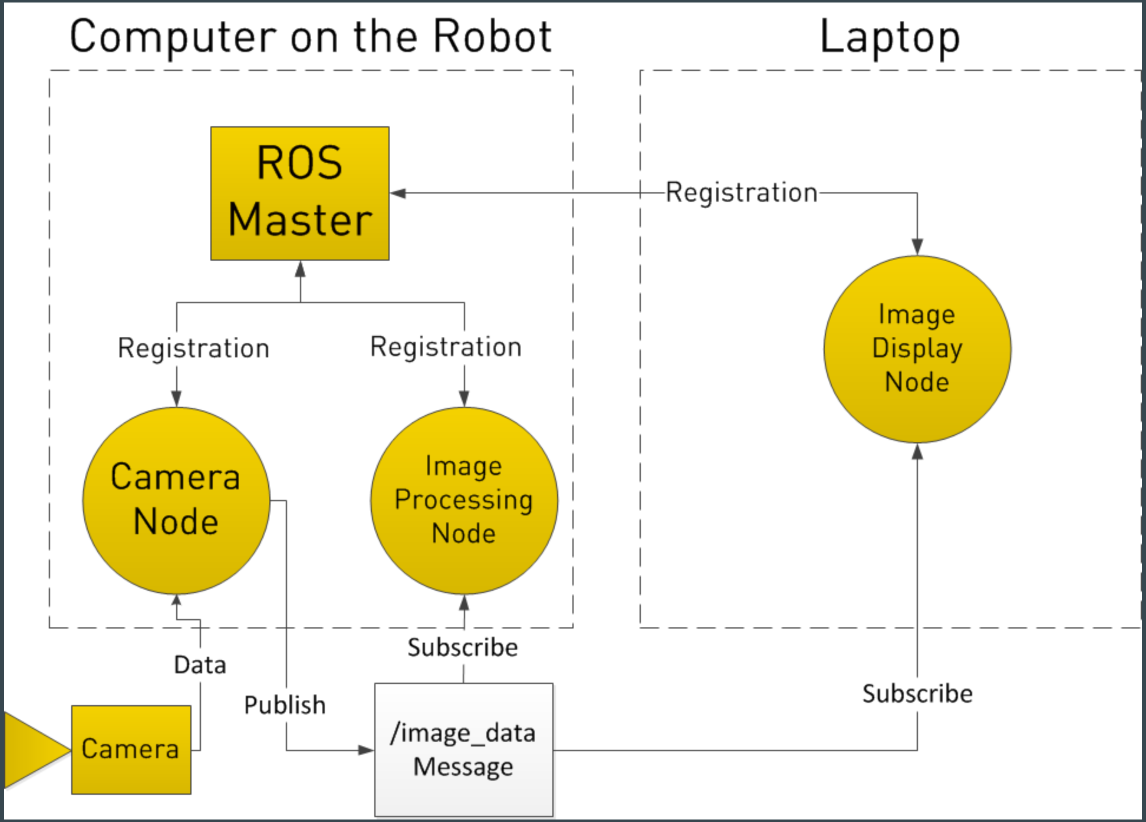
Software Stack

Robot Operating System (ROS)

- Component based middleware framework for robot applications
- Abstracted by
  - Nodes:
    - represent individual component modules
    - C++ programs
    - Can launch several threads implicitly
  - Topics:
    - contain input/output data between nodes

ROS

Simplified example:



Software Stack

- Point-Cloud Library (PCL)
    - Developed to manage point-cloud data
    - Used by Autoware for localization and mapping
    - Localization and mapping error of 10 to 20 cm
    - Implements Euclidean clustering for object detection
- OpenCV
    - Computer vision library for image processing
    - Supports DPM algorithm for object detection
    - Provides API library functions for converting and loading images

Software Stack

CUDA

- Framework for computing on GPUs
- Problem: autonomous driving algorithms are computing intensive
- CUDA improves execution speeds which is essential for real-time performance

Android

- Used for the human-driver interface
- UI displays on a tablet in the car

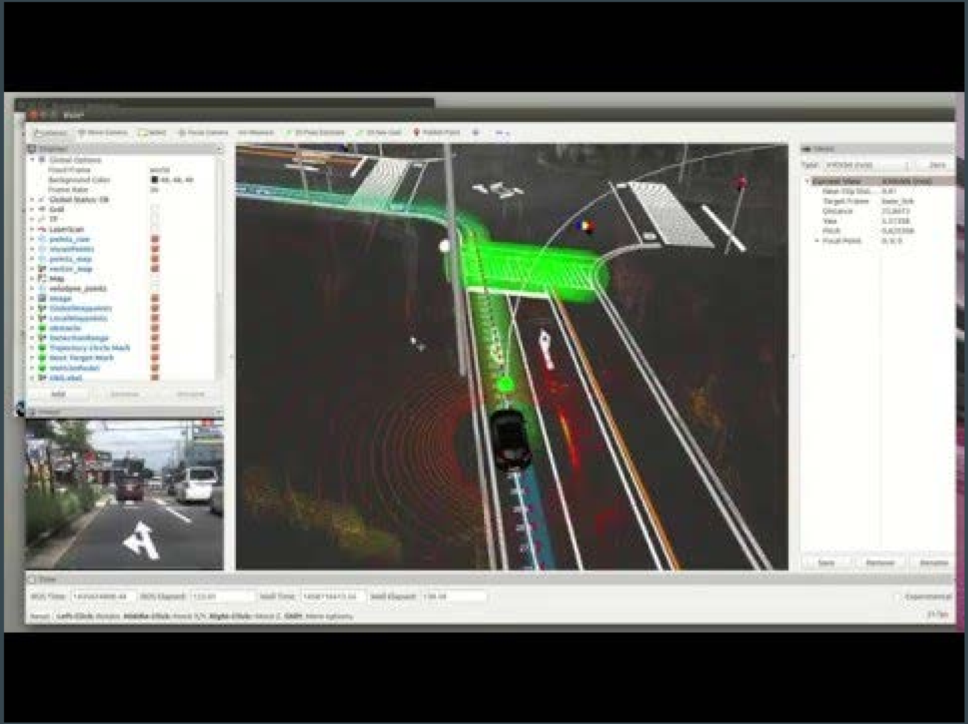
openFrameworks

- Provides displays visualizing the status of th

Datasets

- Problem: a 3D map is needed to localize the vehicle
  - Autoware generates a 3D map
  - This process is very time intensive
- Autoware is able to use 3D maps generated by itself and from third parties
  - Allows for wide use in industry and academia
- Simulation requires datasets
  - ROS provides simulation framework called ROSBAG
    - Used to test functions of autonomous vehicles

ROSBAG Simulation



Performance requirements

- Numerous time constraints in autonomous driving
- Two problems:
  - A* algorithm uses the most time, requiring several seconds or more
    - However, only used for mission planning, runs only when path changes
  - Real-time tasks (e.g., object detection and localization)
    - DPM algorithm spends more than 1000 ms
    - NDT take several ms
- These times must be reduced to operate in a real-time environment
- Using a laptop with Intel i7 and Nvidia GTX980M GPU

Conclusion

The ZMP car, Autoware platform, Robot Operating System

and other introduced hardware and software comprise the first open source platform

for autonomous driving vehicles

Though there are currently latency problems, solutions have been proposed

A designated onboard computer to handle multiple tasks, in real time is essential

Questions/Discussion

How big of a concern is performance really?

How could the authors solution be implemented?

What other algorithms could be used to improve performance

What real time problems would you anticipate in automated cars?

What design changes could improve the car?

What features would you add? (e.g., sensors, more cupholders, etc.)

Was the Prius a mistake when they could have chosen a Lamborghini?