Graphical System Design Case Studies for Developing Autonomous Vehicles

Teppo Myllys
National Instruments
LEGO® MINDSTORMS® NXT
“the smartest, coolest toy of the year”

CERN Large Hadron Collider
“the most powerful instrument on earth”
ROBOTICS PLATFORM

SENSE
- LiDAR
- GPS
- IMU
- Vision Processing
- Filtering

THINK
- Path Planning
- Autonomy
- Kinematics
- Perception
- Localization

ACT
- Holonomic Drive
- Motion Control
- Biomimetic Motion

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Robotics Hardware Architecture

Real-Time
- Planning
  - path planner, behaviors, motion planner
- Perception
  - object classification, localization

FPGA
- safety, filtering, PID motion control

I/O

User Interface
- Health monitor, optional control

Sensors
- LIDAR, camera, GPS, etc

Actuators
- Motors
Case Study: DARPA Urban Challenge

*Odin by Virginia Tech/TORC Technologies*

Virginia Tech

Massachusetts Institute of Technology
Virginia Tech at DARPA Urban Challenge

- The DARPA Urban Challenge required a ground vehicle to autonomously navigate through an urban environment. To complete the course, our fully autonomous vehicle had to traverse 60 miles in less than six hours, while navigating traffic through roads, intersections, and parking lots. At the start of the race, a mission file specified checkpoints on a road network map to be visited in a specific order.
Background of Odin

- Created by Team Victor Tango
- Partnership between Virginia Tech and TORC Technologies
- Won 3rd place at 2007 DARPA Urban Challenge
- Vehicle: 2005 Ford Escape Hybrid
Video: Autonomous Vehicle: Team Victor Tango
Sensing and Actuation

- GPS/INS
- IEEE 1394 Camera
- Single-Plane Laser Rangefinder (LIDAR)
- Drive-by-Wire Signals
- Multiplanar Laser Rangefinder (LIDAR)

Autonomous vehicle based on 3rd place DARPA Urban Challenge winner designed and created by Virginia Tech and TORC Technologies.
Sensors

- IBEO Alasca A0 & XT multiplanar LIDARs (3)
- SICK LMS 291 single-plane LIDAR (4)
- IEEE 1394 cameras (2)
- Novatel Propak GPS/INS (Inertial Navigation System)
- Wheel speed & steering angle from vehicle CAN interface
- Extended Kalman Filter (EKF) used to fuse wheel speed and steering angle data with GPS/INS for ~10cm precision of absolute position
Actuation – Drive-by-wire

• Used stock drive-by-wire system in Ford Escape Hybrid
• Used vehicle CAN bus to send throttle, steering and shifting signals
• Voltage profile of signals reverse engineered using USB data acquisition system (NI CompactDAQ)
Algorithms and Architectures
Algorithms and Architectures

Planning

Route Planner -> Driving Behaviors -> Motion Planning -> Vehicle Interface

Perception

Vehicle Localization -> Road Detection -> Object Classification

Object List -> Dynamic Object Predictor

Sensors

Odometer -> Magnetometer -> GPS/INS -> Vision -> LiDAR

RNDF, MDF, A-priori

Vehicle Localization

Road Network

Speed, Curv.
Network Communications and Control
Network Communications and Control

- SAE AS-4 JAUS (Joint Architecture for Unmanned Systems)
  - Implemented in LabVIEW
  - Interoperable architecture standard for passing messages and status information between subsystems
- SafeStop™ developed by TORC Technologies
  - Independent multi-level wireless emergency stop system for UMS
  - 900 MHz FHSS wireless link with 6 miles of LOS control
- Most sensor data through ethernet
  - Sensors connected to serial-ethernet converter
Embedded Controller Programming

SAE AS-4 JAUS Interoperable Communications

Dual Quad-Core Servers with NI LabVIEW

Multiplanar Laser Rangefinder (LIDAR)

IEEE 1394 Camera

GPS/INS

Single-Plane Laser Rangefinder (LIDAR)

Drive-by-Wire Signals

NI CompactRIO® and NI LabVIEW®

NI Touch Panel with NI LabVIEW

Autonomous vehicle based on 3rd place DARPA Urban Challenge winner designed and created by Virginia Tech and TORC Technologies.
Embedded Controller Programming

• FPGA-based real-time embedded controller (NI CompactRIO) running LabVIEW
  ▪ generate drive-by-wire signals
  ▪ low-level CAN-based vehicle communications

• Dual quad-core HP server running LabVIEW & C++ on Linux
  ▪ decision making and path/motion/route planning modules
  ▪ recognition, detection, driving behavior

• Dual quad-core HP server running LabVIEW on Windows XP
  ▪ image and sensor data acquisition and processing

• Touchpanel on dashboard running LabVIEW
  ▪ change mode of operation b/w autonomous and manual
Case Study: MTT Vakola

- Cropinfra
  - 30 Hectare research Field
  - Everything that’s done on the field with machinery will be logged
  - Fuel Consumption, Use of Fertilizers etc.
  - GPS, CAN, Isobus, Cropinfra Database, Different Sensors etc.
MTT Vakola Croptech-Research Team

- Farm Machinery and Automation
- Intelligent Sensors and Environment
- Safety and Production Control
Case: Automatic working depth control in seed drills: Requirements for sensor, actuator and mechanical components

- Automatic working depth control for drills, which utilizes tractor’s hydraulic valves via standardized ISO 11783 network with an ISO 11783 (ISOBUS) class 3 tractor
- For the automatic working depth control for the case driller
  - Reliable measuring system needed to be implement
  - Development of a working depth model for driller ECU was required
  - Finally development of a prototype driller ECU was needed
In-House Sensor Testing

• Purpose to Measure Volume of Hay Windrow
• Main sensor used was Sick LMS series Scanning Distance laser
• Distance from single point – Polar to Cartesian conversion
In the Field

- Field test arrangement

- Visualisation in LabVIEW after coordinate conversion
Adding more sensors and Data

• Position data from GPS
• Distance data from pulse sensors and from Isobus
• Humidity Sensor – Calculated Volume + Humidity gives the mass of Hay
• Can be fed to Isobus as new Information to be used in other calculations etc.
Layers for Robotics Development

- **Sensing**
  - Image acquisition
  - Sensor data
- **Cognition**
  - Path planning
  - Route planning
- **Perception**
  - Navigation
  - Sensor data interpretation
- **Architecture**
  - System modeling
  - Dynamic/kinematic control
- **Actuation/Mobility**
  - End effector control
  - Bipedal/wheeled mov’t
LabVIEW Robotics

**Software Bundle**
- LabVIEW FPGA
- LabVIEW Real-Time
- LabVIEW Mathscript RT
- LabVIEW CD&Sim
- NI Vision
- NI Soft Motion
- LabVIEW Statechart
- PID Toolkit
- System ID Toolkit

**Drivers**
- Sensor drivers
- Actuator drivers
- Driver project wizard

**Robotics IP**
- Search algorithms
- Robotics visualization
- Obstacle avoidance
- Kinematics
- Robotics Examples

**“New” Experience**
- Getting started wizard
- RIO hardware wizard
- Template architectures

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Sensing
Connectivity
*MobileRobots, Skilligent, Cogmation*
Protocols
*JAUS, NMEA, FPGA*
Path Planning
Obstacle Avoidance
Steering
Robotic Arm
*Open Source Robotics Toolbox*
Download additional algorithms
Sensor Drivers

- IR Sensors
- GPS Sensors
- LIDAR Sensors
- Stereo Vision
- Radar Sensors
Sensor and Actuator Drivers

List of Drivers

- LIDAR (Hokuyo, SICK, Velodyne)
- Infrared (SHARP)
- Sonar (Devantech, MaxSonar)
- Ultrasonic Rangefinder (Parallax Ping))
- GPS (Applanix, Garmin, NavCom, u-Blox)
- IMU (Crossbow, MicroStrain, Ocean Server)
- Compass (Devantech)
- Light (Vishay)
- Encoder (Maxon)
- Thermal (Devantech)
- Motors (Dynamixel, Lynxmotion, TI MDL BDC24)

- Servo Motors (Parallax, Hitec HS400)
- Digital Compass and 3-axis Tilt (PNI FieldForce)
- DC Motor Controller
- Text to Speech device (V-Stamp)
- RFID Reader (APSX RW Series)
Trends in Autonomous Systems Design

Sequential → Parallel
Single Core → Multi Core
Object-Oriented → Object and Actor Oriented
Fixed Personality → Adaptable / Reconfigurable Personality
Homogeneous Processing → Heterogeneous Processing
Local Processing → Distributed Processing
Textual Programming → Hybrid Graphical & Textual Programming
Low-Level Tools → Platform-Based Tools
For more information and case studies visit:

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