Truck CACC Project Status:
Development of CACC Control System

California PATH Project Team
06/24/2015
Outlines

• Overall Control System Structure
• Control System Hardware
• Control System Software
• System Modeling and Control
• Control Actuation Strategy
• Control Logics for Different Scenarios
• Scenarios Preliminarily Developed Now
• Performance Difference Observations
• Next Step
Overall Control System Structure
Main Data Flow between PATH Computer and XPC

PATH Linux Laptop

PATH PC-104 QNX RTOS

Volvo XPC: sensor data processing

Fused sensor data

J-Bus interface

Engine/brake control commands

Mini-ITX

Tablet DVI
Expected Truck Control System Structure, on 3/4/15

- Dual Antenna
- 1Hz GPS
- WiFi Box
- 5Hz GPS
- Tablet
- Digitized Video Cameras
- DSRC radio
- PATH Linux Laptop
- PATH PC-104 QNX RTOS including data logging
- Emergency switch
- Transmission Contr. Mod.
- Brake Syst. Contr. Mod.
- Eng. Contr. Module
- Volvo XPC
- Radar & camera
- Production components
- Truck info
- Wide angle Lidar
- Mini-ITX including video logging
- Digitized Video Cameras
- RCA
- PATH
- PATH Eng. Contr. Module
- PATH Brake Syst. Contr. Mod.
What we have now for Truck Control System, 6/24/15

- Single Antenna
- WiFi Box
- 5Hz GPS
- PATH PC-104 QNX RTOS including data logging
- WSU DSRC
- PATH Linux Laptop
- Emergency switch
- Ethernet
- Digital I/O
- J-Bus 1
- J-Bus 2
- Volvo XPC
- Truck info
- transmission Contr. Mod.
- Eng. Contr. Module
- Brake Syst. Contr. Mod.
- Radar & camera
- production components
What we have now for Truck Control System, 6/24/15

**PATH PC-104**
- QNX RTOS including data logging
- Ethernet
- Digital I/O
- J-Bus 1
- J-Bus 2

**Dual Antenna**
- WiFi Box
- 5Hz GPS

**PATH Linux Laptop**
- WSU DSRC
- Ethernet
- Emergency switch

**Volvo XPC**
- Transmission Contr. Mod.
- Brake Syst. Contr. Mod.
- Radar & camera

**Eng. Contr. Module**

**Truck info**

**Production components**
Control System Hardware

- **PATH PC-104 computer with large enough SD, running**
  - Operating system: QNX 6.0
  - Interface with 2 CAN Buses: 1 for truck info, 1 for X-PC sensors
  - DSRC radio with antenna (Denso WSU now, new ITRI later)
  - 5 Hz GPS
  - Connecting with a laptop for system development
  - Emergency switch to cut-off the link with J-Bus
  - Interfacing with J-bus
  - Volvo XPC connection to J-Bus
  - Control data logger
  - Laptop for control scripts
  - Laptop table
- **Power supply for all components**
Control System Hardware

• 1 Laptop
  – DVI Display
  – Video camera
  – Serial connection with PC-104
  – Video and DVI data logger
Added Hardware

Old PC-104 running QNX real-time operating system currently in use

New PC-104 computer to run QNX real-time operating system

Emergency switch to cut-off link with J-Bus

PATH Laptop for system development

5 Hz GPS
Added Hardware
Built-in Radar and Video Camera

Volvo Built-in Radar

Volvo built-in video camera
Control messages:
PCI-104 -> EMS:
TSC1_E_A
PCI-104 -> EMS:
TSC1_ER_A
PCI-104 -> EBS:
XBR_bendix
PC-104 Software Structure

BR = Blocking Read
TW = Triggered Write
PR = Periodic Read
PW = Periodic Write
Control System Software Structure

- 5Hz GPS Data
- Driver cmd SW
- Maneuver Coordination: desired position and velocity
- Truck Longitudinal Dynamics: engine, driveline, tire, aerodynamic drag, etc ➔ desire torque
- Engine torque control
- Brake system control: engine brake, air brake
Control System Modeling – Freightliner (prior project)
Control System Modeling – Volvo Truck
Control Actuation Strategy

• PATH PC-104 Computer directly interface with J-1939 Bus for control actuation
  – Engine torque control
  – Engine retarder control (braking)
  – EBS Control to be used
  – No Transmission Retarder
Control Logics for Different Scenarios

Transitions between Driving Modes

- CACC Driving
  - Transition from CACC to manual
  - Transition from Manual to CACC
  - Transition from CACC to ACC

- Manual Driving
  - Transition from manual to ACC

- ACC Driving
  - Transition from ACC to manual
  - Transition from ACC to CACC
Control Logics for Different Scenarios

Control Strategy for vehicle Following: Veh 1

- DVI: T-Gap
- Determine D-Gap
  - Yes: has front veh
  - No:
    - Yes: Determine \( v_{\text{des}}(k) \), \( d_{\text{des}}(k) \)
    - No:
      - Determine \( v_{\text{des}}(k) \), \( d_{\text{des}}(k) \)
      - Controller: \( a_{\text{des}}(k) \), \( t\text{orq}_{\text{des}}(k) \)
      - Torque command to J-Bus

- Current meas \( d(k-1), v(k-1) \)
- \( I = 1 \) (Veh Positioning)

- Cut-in? Other scenarios?
  - Yes: Transition control for cut-in; determine \( v_{\text{des}}(k) \), \( d_{\text{des}}(k) \) to reach D-Gap
  - No:
    - Determine \( v_{\text{des}}(k) \), \( d_{\text{des}}(k) \)
    - Controller: \( a_{\text{des}}(k) \), \( t\text{orq}_{\text{des}}(k) \)
    - Torque command to J-Bus
Control Logics for Different Scenarios

**Control Strategy for vehicle Following: Veh 1, I>1**

1. **DVI: T-Gap**
   - Determine D-Gap
     - Determine \(v_{des}(k)\), \(d_{des}(k)\)
     - Controller: \(a_{des}(k)\), \(torq_{des}(k)\)
     - Torque command to J-Bus
   - Yes: Transition control for cut-in; maintain CACC, determine \(v_{des}(k)\), \(d_{des}(k)\) to reach D-Gap
     - Set: \(I=I+1\)
     - String size reset
   - No: Transition to ACC Control:
     - Set: \(I=1\)
     - String size reset

2. **Veh Positioning**
   - Current meas \(d(k-1), v(k-1)\)
   - Cut-in?
     - Yes: Is cut-in CACC or DSRC veh
     - No: Transition to ACC Control:
Scenarios Preliminarily Developed Now

- Very crude system modeling based on guess and experience
- Very crude feedback control for vehicle following
- Transition between manual & automatic (CC for veh 1)
- Adaptive Cruise Control (ACC)
  - Vehicle 1 manually driving (T-Gap: 1.6s)
  - Vehicle 1 automatically driving (T-Gap: 1.6s, demo)
- Cooperative Adaptive Cruise Control (CACC)
  - Vehicle 1 manually driving (T-Gap: 1.3s)
  - Vehicle 1 automatically driving (T-Gap: 1.1s, demo)
- Not necessarily that all the maneuvers can be extended to 3 trucks due to string stability issues (TBD)
Performance Difference Observations

- Drive mode in the following plots
  - 0: stopped
  - 1: manually driving
  - 2: automatically driving
    - CC: without front vehicle
    - ACC: with front vehicle
  - 3: CACC
Performance Difference Observations: ACC, Veh 1
Automatically Driven
Performance Difference Observations: ACC, Veh 1
Manually Driven
Performance Difference Observations: CACC, Veh 1
Automatically Driven
Performance Difference Observations: CACC, Veh 1 Manually Driven (HIA)
Next Step

• Data collection for model refining
• Adding missing hardware and software
  – New PC-104, new DSRC, GPS, air brake control, ...
• Refining controller for
  – Robustness
  – Smoothness
  – Higher speed
  – Maintain and improve string stability
• Developing 3rd truck and add to string (hardest part)
• Developing more following scenarios
• Challenges: *flexibilities and robustness of controller for handling different maneuvers on-the-fly*
Discussion