SenseDSL: Automating the Integration of Sensors for MCU-based Robots and Cyber-Physical Systems
2007 DARPA Urban Challenge

Autonomously driving vehicle *Caroline* participating in the 2007 DARPA Urban Challenge.
Experimental Miniature Vehicle Fleet
Experimental Miniature Vehicle Fleet

Vehicle

Infrared

OOD

A&G

L

Camera

Ultra sonic

Infrared

Ultra sonic

Ultra sonic
<table>
<thead>
<tr>
<th>Component</th>
<th>Component ID</th>
<th>Connection Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>RC Vehicle</td>
<td>1/10 scale electrically driven on-road vehicle</td>
<td></td>
</tr>
<tr>
<td>Infrared Sensor</td>
<td>SHARP GP2D120</td>
<td>ADC</td>
</tr>
<tr>
<td>Ultrasonic Sensor</td>
<td>Devantech SRF08</td>
<td>I2C</td>
</tr>
<tr>
<td>Camera</td>
<td>Logitech c525</td>
<td>USB</td>
</tr>
<tr>
<td>Steer/Servo</td>
<td></td>
<td>PWM</td>
</tr>
<tr>
<td>ESC</td>
<td>1/10 Brushless ESC</td>
<td>PWM</td>
</tr>
<tr>
<td>Motor</td>
<td>1/10 Brushless Motor</td>
<td></td>
</tr>
<tr>
<td>LED Board</td>
<td>Self-assembled</td>
<td>ADC</td>
</tr>
<tr>
<td>Razor Board</td>
<td>Razor-9DoF-IMU</td>
<td>UART</td>
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<tr>
<td>Discovery Board</td>
<td>STM32F4-Discovery</td>
<td>USB</td>
</tr>
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<td>Application Board</td>
<td>PandaBoard ES</td>
<td>USB</td>
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<tr>
<td>RC-Handset</td>
<td>A3-STX Deluxe F.H.S.S</td>
<td>Wireless</td>
</tr>
<tr>
<td>RC Receiver</td>
<td>A3-RX Deluxe F.H.S.S</td>
<td>Wireless</td>
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</table>
Engineering the HW/SW interface

- Embedded System Hardware Manual
- Embedded System Data Sheets
- Domain-specific PIN Constraints
Engineering the HW/SW interface

- Total 14,689,111 configuration possibilities
- Verification of a given pin assignment configuration
- Finding a feasible/all possible/best pin assignment configuration for the interface board

\[
C_{|M|=1} = \sum_{k=1}^{L} \binom{|N|}{k} = \sum_{k=1}^{L} \frac{|N|!}{(|N|-k)!k!}
\]

\[
K(n, m) = \begin{cases} 
1 + \sum_{p=1}^{n} * K(p, m-1) & \text{if } m > 1, \\
1 & \text{otherwise}
\end{cases}
\]

\[
C_{|M|} = \sum_{k=1}^{L} \binom{|N|}{k} * K(k, |M|)
\]
Engineering the HW/SW interface

- Camera
- LED Board
- Braking LEDs
- Flashing LEDs left
- Flashing LEDs right

PandaBoard ES + Linux

- Wheel Encoder 1 Sensor A
- Wheel Encoder 2 Sensor A
- Wheel Encoder 2 Sensor B
- Wheel Encoder 2 Sensor B
- RC-Receiver
- ESC
- Motor
- Steer

STM32F4 Discovery Board + ChibiOS

- Infrared
- Ultrasonic
- Ultrasonic
- Ultrasonic
- PB6 (SCL)
- PB9 (SDA)
- PD8 (TX)
- PD9 (RX)

- ADC
- I²C
- ICU
- PWM
- UART
- USB
Engineering the HW/SW interface
Model Checking & Code Generation

```c
board STM32F4DiscoveryBoard {
  sensor IRFront returns uint16 {
    id = 17;
    type = analog; // infrared
  }
  sensor IRFrontRight returns uint16 {
    id = 18;
    type = analog;
    delay = 60;
  }
  sensor USRear returns uint8 {
    id = 19;
    type = i2c; // ultrasonic
    address = 0xE6;
    delay = 40;
    prio = +2;
  }
  sensor WheelEncoder returns uint32 {
    id = 20;
    type = icu;
  }
}
```
Model Checking & Code Generation

```c
board STM32F4DiscoveryBoard {
    sensor IRFront returns uint16 {
        id = 17;
        type = analog; // infrared
    }
    sensor IRFrontRight returns uint16 {
        id = 18;
        type = analog;
        delay = 60;
    }
    sensor USRear returns uint8 {
        id = 19;
        type = i2c; // ultrasonic
        address = 0x6E;
        delay = 40;
        prio = +2;
    }
    sensor WheelEncoder returns uint32 {
        id = 20;
        type = icu;
    }
}
```
Conclusion

• HW/SW integration is a constraint-satisfaction problem

• Engineering the HW/SW interface with MDE:
  – Our embedded system: >14.5 million configuration possibilities
  – Automated verification of a given pin assignment configuration
  – Side effect: Finding a feasible/all possible/best pin assignment configuration for the interface board

• Intuitive workflow:
  – Description of facts
  – Description of desired setup
  – Let model transformation automagically do the rest!

http://www.christianberger.net/uproxy