CARMA: Towards Personalized Automotive Tuning

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Sensys 2011
Introduction

Networked Sensing
- Smart Grid
- Smart Building

Smartphones
- Context awareness
- Participatory sensing

Automobiles
- On-board sensing
- Personalized tuning
Sensing and Control in an Automobile

Automobiles are highly customizable but this capability is not exposed to the user.

Current Practice: Fixed Control Parameters

Factory defaults cannot cover all possible conditions
Our Goal: Flexible Personalized Tuning

CarMA can optimize for individual trips
Can Personalized Tuning Be Effective?

Impact of route characteristics?

Impact of driving behavior?

Interstate Route  
Hill Route  
Street route
Can Personalized Tuning Be Effective?

Fuel economy for two cars on different routes (with different conditions)

Intrinsic variability

Extrinsic variability

Exploitable by personalized tuning
Background: Scanning and Tuning

Client device — On-board diagnostics (OBD-II) — Engine control unit (ECU)

**Table: Desired Idle RPM/Value**

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Transmission not engaged</th>
<th>Transmission engaged</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coolant Temperature</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-20°C</td>
<td>1200</td>
<td>1200</td>
</tr>
<tr>
<td>0°C</td>
<td>1106.05</td>
<td>964.65</td>
</tr>
<tr>
<td>20°C</td>
<td>1022.27</td>
<td>860.35</td>
</tr>
<tr>
<td>40°C</td>
<td>904.69</td>
<td>768.75</td>
</tr>
</tbody>
</table>
Contributions: CarMA

**CARMA:** A smartphone-based, make and model-independent platform providing **programming abstractions for scanning and tuning**

- **Wireless connectivity**
- **On-Board Sensing**
- **Programmability**

Fosters ecosystem of car modifications
Contributions: Sample Apps

Implementation of sample apps that allow non-expert users to personalize and automatically optimize cars for different drivers and/or route conditions.

- Improve responsiveness for hilly route
- Maximize fuel efficiency
- Support user diversity
- Enforce safer driving behavior
Contributions: Benefits of Personalized Tuning

A demonstration of personalized tuning that can exploit extrinsic variability to achieve significant fuel efficiency or responsiveness gains
CARMA Architecture
Scanning Subsystem

1. Request: vehicle speed sensor
2. Response: 07 00 48 6B 10 41 0D 28
   Vehicle Speed Sensor = 40 km/h

Introduction
Motivation
Architecture
Evaluation
Conclusion
Tuning Subsystem

setRPMLimit();
commit();
prepare();

Reverse Engineering
Download routine
Level of Abstraction

ECU memory

Motivation
Architecture
Evaluation
Conclusion
**Motivation**

- **Architecture**
- **Evaluation**
- **Conclusion**

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**Mod**

<table>
<thead>
<tr>
<th>Mod</th>
<th>Response</th>
<th>Economy</th>
<th>Safety</th>
</tr>
</thead>
<tbody>
<tr>
<td>DisableEGR</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>EnrichMixture</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>IncreaseSparkTiming</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>AdjustShiftDownPoints</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>LimitRPM</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>DecreaseShiftTime</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

---

**Tuning Subsystem: ModAPI**

**Client code**

```java
 tuner = ATuner.Stub.asInterface(service);
 tuner.loadCurrentSettings()
 tuner.applyMod(ModNames.LimitRPM, rpmVal)
 tuner.commitChanges()
```

**CARMA code**

```java
 new TableSetMod(
   ECUTableName.Disable_All_Injectors_High_MPH,
   0, 0, 0, 2, 255),
 new TableSetMod(
   ECUTableName.Disable_All_Injectors_High_MPH,
   1, 1, 0, 2, limit + 1),
 new TableSetMod(
   ECUTableName.Disable_1 Injector_High_MPH, limit),
 new TableSetMod(
   ECUTableName.Disable_2_ Injectors_High_MPH, limit)
```
Evaluation Goals

1. Does CarMA raise the level of abstraction?
   - Implementation of sample applications
   - Micro-benchmarks

2. Does CarMA provide significant fuel efficiency gains?
   - Test runs using route-specific fuel efficiency optimizations on five different routes
   - Comparison of the recorded sensor data from baseline and modified runs
Evaluation: Applications

- **Scan App**: 98 LOC
- **Tune Wizard**: 214 LOC
- **Route Evaluator**: 408 LOC
- **Valet Mode**: 60 LOC
- **Driver Customizer**: 76 LOC
Evaluation: Tune Wizard

Alice

Enable EGR
Increase torque timing
Limit RPM to 5000
Limit RPM to 3000
Evaluation: Fuel Efficiency Gains

- Recorded data for baseline runs and runs using modifications
- Experimented with multiple drivers
- Recorded data for more than 1100 miles of driving

- Speed limit
- Elevation gain
- Traffic lights
- Congestion
- Max. grade
Experimental Results: Fuel Economy

Fuel economy for one driver

<table>
<thead>
<tr>
<th>Trip</th>
<th>Baseline</th>
<th>Modified</th>
<th>Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>17.6</td>
<td>18.4 (+4.4%)</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>19.7</td>
<td>22.2 (+12.8%)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>22.0</td>
<td>24.4 (+11.1%)</td>
<td></td>
</tr>
<tr>
<td>4a</td>
<td>20.3</td>
<td>23.1 (+13.7%)</td>
<td></td>
</tr>
<tr>
<td>4b</td>
<td>14.8</td>
<td>16.7 (+13.3%)</td>
<td></td>
</tr>
</tbody>
</table>

Fuel economy improved by 11% on average

Would save more than $18B in the US annually
Experimental Results: Validating Applications

RPM vs. throttle pos. for DriverCustomizer

Aggressive driving behavior is prevented
Related Work

- Sensing
  - Torque
    - Powr Tuner
      - CarMA
    - Mechanics
      - GreenGPS
- Control
- Analysis
Conclusions

CarMA provides programming abstractions for scanning and tuning automobiles via mobile devices

Usable by non-experts for personalized tuning

CarMA apps can achieve significant fuel efficiency gains by inhibiting aggressive driving behavior and enforcing limits
Future Work

Extending CarMA for a broader range of makes and models

Adding safety mechanisms to prevent accidental or malicious damage to vehicles using CarMA
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Sensys 2011
Improving the State of the Art

Expressivity

Fuel economy / Performance modes

Complexity

Specialized tuning software

C_{ARMA}
Security Considerations

Implemented functionality

- Checks for conflicting modifications
- Definition of safe value ranges for parameters

Additional ideas

- Application certification
- Mandatory "kill switch"

Value range (Desired Idle RPM; single cell)
Experimental Results: Economy variability

Impact of mods depends on “old” driving behavior.
Experimental results: Speed and RPM limits

**Speed on trip 3**

- Speed limit is enforced

**RPM CDF for trip 4B**

- RPM long tail is cut
Background: Scanning & Tuning
OBD-II Port