Driving Intelligence for Safer Automobiles

Hideo Inoue
Toyota Motor Corporation
The History of the Automobile

1769

The world's first automobile:
A steam-powered vehicle

Invented by Nicolas-Joseph Cugnot

Today (from 2006)

Pre-collision system (PCS)

Emergency avoidance of objects and pedestrians
Our perspectives of safe & secure driving

(1) Mitigation
* Airbag
* Seatbelt
* Body structure

(2) Emergency avoidance
* Rear-end collision avoidance
* Pedestrian protection
* Head on collisions
* PCS, ESC, ABS, etc.

Time

Today

Tomorrow

Driving quality enhancement based on safety technologies

Integrated Safety
Our perspectives of safe & secure driving

(1) Mitigation
- Airbag
- Seatbelt
- Body structure

(2) Emergency avoidance
- Rear-end collision avoidance
- Pedestrian protection
- Head on collisions
- PCS, ESC, ABS, etc.

(3) Avoidance of human-error induced accidents
1) Distraction, fatigue, drowsiness, heart attacks, etc.
2) Less stress in monotonous driving situations
e.g., highway/interstate driving/trips, congested/stop-and-go traffic
3) Elderly/disabled drivers
Our research into intelligent driving technology

- Monitor around the vehicle and predict risks.
- Find and follow safe routes

From 2005:
Learn from skilled drivers
→ Verify potential of autonomous vehicle dynamic controls

From 2007:
Pursue sensing, perception, and recognition technology
Two topics for tomorrow

1. **ADAS with Driving Intelligence for a Safer and More Secure Traffic Society for Elderly Drivers (S-Innovation Project in Japan)**

2. **Traffic Congestion and Highway Driving Intelligence**
Two topics for tomorrow

1. **ADAS with Driving Intelligence for a Safer and More Secure Traffic Society for Elderly Drivers (S-Innovation Project in Japan)**

2. **Traffic Congestion and Highway Driving Intelligence**
Motivation and objectives: Overcoming fear of driving

- Deterioration in driving ability reduces self-confidence in driving.
- However, elderly drivers are highly motivated to improve QOL.
- Intelligent driving systems can help to compensate for this deterioration in physical ability and overcome the fear of driving.

Fig. 1 Reaction of drivers to active safety system (Experimental study using Toyota Driving Simulator)

Drivers over age 60 recognized the warning but did not brake.

The older the driver, the higher the ratio that could not recognize the warning.

Elderly drivers have high motivation to drive.

Fig. 2 Vehicle necessity

- Can be used anytime, anywhere
- Trains and buses cannot be used
- Trains and buses limit time
- Trains and buses take too much time
- Love to drive for fun
ADAS concept with driving intelligence

Shared control between an expert driver model and actual driver

- **Driver-in-the-loop** ADAS concept (not fully automated)
- Driver can override the system if necessary
- Driver-vehicle cooperative system $\geq$ Experienced driver

**Haptic-based control is important.**
Safe driving concept: Obtaining anticipatory driving information

- Learn from the knowledge and experience of experienced drivers

1. Determine how to drive
2. Predict hidden risks
3. Emergency avoidance

Knowledge/experience-based information (mechanical learning) / external information (maps, V2X)

Higher sensor performance
Innovative sensing/recognition/judgment algorithms

Anticipatory driving information

10 seconds ahead
5 seconds ahead
2.5 seconds ahead
1 second ahead
Immediate object

Forward distance
m

300
200
100

Prediction
km/h

Accident!

Collision avoidance
Damage mitigation PCS

Awareness of in-vehicle sensors

Innovative sensing/recognition/judgment algorithms

Learn from the knowledge and experience of experienced drivers

(2) Predict hidden risks

10 sec
5 sec
1 sec
100 msec
10 msec

(1) Determine how to drive
(2) Predict hidden risks
(3) Emergency avoidance

Stopped vehicle
Traffic restriction information
Vehicle path
Intersection/crossing
Road friction
Road profile
Merge
Tail of congestion

Speed

300
200
100
60
20
100

300
200
100

Integration Safety
Control scheme of experienced driver model

Human driver

Vehicle motion

Driving environment

Driver maneuver

Vehicle motion

Vehicle position and heading

Vehicle speed

Desired trajectory

Path/speed modification

Risk potential prediction

Trajectory planner

Digital map
Camera
Radar

Objects
Location

Knowledge-based DB

Artificial intelligence

(1) Normal driving model

Obstacle

(2) Risk prediction model

Acc. OFF

Brake ON

Steer

Brake

(3) Emergency crash avoidance model

Desired speed

Safe speed control

Distance control

Course tracking

Steering command

Accelerator command

Brake command

Shared control

Actuator control unit

Integrated Safety
Driving intelligence: (1) Normal driving control

(1) Normal driver model for longitudinal and lateral direction, i.e., car following and lane keeping, integrating the risk potential field

Sensing the position of the driver’s vehicle using the curb measured by laser radar, combined with GPS/digital map

Speed control using curvature and lane tracking

Car following control using repulsive and attractive forces in the risk potential field
Near-miss incident data collected in the real world can be used for the assessment and advanced development of autonomous driving intelligence systems.
(2) Risk prediction model

**Risk prediction model**: Defensive driving, object motion prediction, hazard anticipation

Contour of risk potential generated from surroundings and on-road objects

Driving intelligence must predict the possibility of the appearance of pedestrians from **behind an object** and determine the optimum safe speed.
Demonstration of driving with risk prediction

(1) Normal driving control of longitudinal and lateral dynamics, i.e., car following and path tracking
(2) Risk potential based control including hazard anticipation to minimize collision risk
(3) Emergency avoidance control by braking and steering

Anticipatory driving intelligence is demonstrated using a Toyota Prius as shown below.

No pedestrian appears (2) Risk potential based control

Pedestrian appears from behind the parked car (2)+(3) Emergency avoidance
Effect of defensive driving by driving intelligence

- Collision avoidance performance can be effectively enhanced by introducing risk prediction into the driver model (Fig. 2).
- The driving intelligence model can express expert driver behavior (Fig. 1).

Fig. 1: Comparison with data of expert drivers

![Graph showing comparison with expert drivers](image1)

**Synthesis of defensive driving model** by learning expert driver data for enhancing driving safety.
(3) Emergency avoidance control: New Pre-Collision Safety (PCS) system

- Steering control added to conventional emergency brake.
- System controls the steering if a collision cannot be avoided by braking.
Conceptual diagram of ADAS with driving intelligence

Vehicle motion

Road

Driver

Maneuver

Driving Intelligence

Sensor Fusion and World Model

Course

Corner/Blind spot

Obstacle

Risk Potential

Motion Planning Algorithm

Reference maneuvers

Shared Control

Vehicle

Emergency avoidance control
Smaller 3D Lidar

**SPAD Lidar**

Output by dist. image

Smaller/highly reliable/optimized processing

* SPAD: Single Photon Avalanche Diode, Lidar: Light Detection And Ranging
Two topics for tomorrow

1. ADAS with Driving Intelligence for a Safer and More Secure Traffic Society for Elderly Drivers (S-Innovation Project in Japan)

2. Traffic Congestion and Highway Driving Intelligence
Situation of highways in Japan

**Congestion**

- Traffic overconcentration: 68%
  - Others: 2%
  - Construction: 1%
  - Accident: 29%
  - Other: 4%
  - Toll gate: 2%
  - Junction: 9%

*Sag-tunnel: 53%*  

*2007*

**Accidents**

- Moving car: 23%
- Single vehicle: 14%
- Collision: 9%
- Other: 7%
- Vs. person: 1%
- Stopped car in lane: 35%
- Stopped car at toll gate: 7%
- Rear-end collisions: 67%

*2008*

**Targets**

- Reduction of traffic congestion
- Traffic accidents
- CO₂

**Global & local driving intelligence**

- V2X, ACC/cooperative ACC
- Smart highway traffic system
V2V: Cooperative Adaptive Cruise Control (C-ACC)

- With millimeter-wave radar, vehicle to vehicle communication capabilities (760 MHz) have been added to ACC to maintain an appropriate distance between leading and following vehicles.
- C-ACC provides a greater margin of safety for the driver, helps to prevent waves of deceleration, and contributes to reduced highway traffic congestion.

Fig. 1 Control overview

Decelerating (90 km/h → 30 km/h, 0.2 G)

(1) Human driver
(2) ACC
(3) C-ACC

Fig. 2 String stability performance of C-ACC (field operational test)
Time headway to ensure a basic traffic flow rate of **more than 2,000 veh/h** depending on the ACC penetration rate.

Traffic congestion reduction rate = \frac{\text{Congestion before widespread adoption of ACC}}{\text{Congestion after widespread adoption of ACC}}
Automated highway driving

Automated Highway Driving Assist (AHDA)
Automated driving technology: Gate-to-gate
Summary: Cyber-physical system for intelligent driving systems

- **Global driving intelligence**
  - Near-miss data analysis/accident analysis
  - Enhanced map for dynamic usage
  - Traffic congestion prediction
  - etc.

- **ICT: Info. & communication technology**
  - V2X

- **Local driving intelligence**
  - ADAS with autonomous driving intelligence

**Big data**

- Travel conditions database
- Human factor database

**Vehicle**

- Fun to drive
- Accident avoidance
- Optimum eco-driving

- Feedback
Expectations for non-volatile memory

- Integrated vehicle control
- Advanced driver assistance
- Connected driving
- Automated driving

20XX year
Memory size increasing

Non-volatile memory

Calibration
Performance
Reliability

Power train

Vehicle

Flash Memory Summit 2015

Flash-memory for current systems
- Retention period: over 20 years
- Writing times: over $10^5$ times
- Computing power (inst-fetch/data-ope)
- Sleep & wake up power reduction

- New NV-memory for next-gen systems
- Huge data storage for machine learning
  - Localized map model, sensor fusion model, motion planning, drive model, etc.
- Random access speed
- High reliability
Rewarded with a smile
by exceeding your expectations

Thank you for your kind attention!