TATA MOTORS EUROPEAN TECHNICAL CENTRE

Tata Motors Autonomous Vehicle -Function Development and Testing



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TATA MOTORS EUROPEAN TECHNICAL CENTRE









Overview

- Introduction
 - Tata/TMETC
 - Autonomy
 - UK Autodrive
- TMETC Autonomous Hexa Architecture
 - Functional/Hardware/Software
- Autonomous Functions (Sensing/Perception/Planning/Control)
 - Global/Behaviour/Trajectory Planning
 - Control Options
 - Model Predictive Control
- Experiences
 - Time Issues
 - Data Logging and Visualisation
- Conclusion





The Tata Group EUROPE Jaguar Land Rover Taj Hotels Resorts and Palaces NORTH AMERICA Tata Capital Jaguar Land Rover Tata Chemicals Europe Taj Hotels Resorts and Palaces Tata Communications Tata Business Support Services Tata Consultancy Services Tata Chemicals North America Tata Elxsi **Tata Communications** Tata Global Beverages Tata Consultancy Services Tata Interactive Systems Tata Elxsi Tata Limited Tata Global Beverages Tata Motors European Tata Interactive Systems **Technical Centre Tata International** Tata Steel Europe Tata Sons North America Tata Technologies Tata Steel Europe TKM Global GmbH Tata Technologies **MIDDLE EAST and NORTH AFRICA Rest of AFRICA** Jaguar Land Rover Jaguar Land Rover Taj Hotels Resorts and Palaces Taj Hotels Resorts and Palaces JOI **Tata Communications** Tata Africa Holdings Tata Consultancy Services Tata Chemicals Magadi **Tata Consulting Engineers** Tata Consultancy Services Tata Elxsi Tata Consulting Engineers Tata Global Beverages Tata Global Beverages Tata Interactive Systems Tata International Distribution Operations in more than 100 countries Tata Motors Tata Motors (SA) Tata Power Tata Power Tata Projects Tata Projects Tata Steel **Titan Company** Tata Technologies 660,000 employees Tata International West Asia DMCC AUSTRALIA SOUTH AMERICA **Titan Company** Jaguar Land Rover Jaguar Land Rover TM International Logistics Tata Communications Tata Group \$100bn turnover Ballis Voltas Tata Consultancy Services **Tata Communications** York Group Tata Consultancy Services Tata Global Beverages Tata Motors Tata International INDIA Tata Motors \$42bn turnover Tata Motors Tata Power Headquarters for majority of Tata companies, including promoter Tata Steel holding company Tata Sons TM International Logistics

CHINA Chery Jaguar Land Rover Automotive Jaguar Land Rover China Nanjing Tata AutoComp NatSteel Xiamen Tata Communications **Tata Consultancy Services** Tata Global Beverages Tata Projects Tata Sons China Tata South East Asia Tata Steel Asia Tata Steel International Tata Technologies **TKM Global China** TRL Krosaki Refractories York Transport

SOUTH EAST ASIA,

EAST ASIA and SOUTH ASIA Jaguar Land Rover NatSteel Holdings Taj Hotels Resorts and Palaces Tata AutoComp Tata Capital Tata Chemicals International Tata Communications Tata Consultancy Services Tata Daewoo Tata Global Beverages Tata International Tata Motors Tata NYK Tata Petrodyne Tata Power International Tata Steel Global Holdings **Tata Steel Thailand** Tata Technologies Titan Company TM International Logistics **Trust Energy Resources** Voltas York Group





Tata Motors European Technical Centre

- Created 2005
- Based in Coventry
- Wholly-owned subsidiary of Tata Motors
- Research & development principally for Tata Motors
- Engineering Centre, Design Studio, Workshops
- 180-strong workforce











Autonomy and ADAS Terminology

Advanced Driver Assistance Systems (ADAS)



AEB (Automatic Emergency Braking)



LDW (Lane Departure Warning)



ACC (Automatic Cruise Control)



Self Parking

Autonomous Car

Driverless or robotic car capable of sensing its environment and navigating without human input

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SAE Levels of Autonomy

	Adaptive Cruise Control	Automatic Emergency Braking					
	Lane Keeping Assist	Traffic Jam Assist					
	Longitudin	al Driving	Automatic Emergency Braking and Steering	Highway Pilot			
	Lane Change Assist		Longitudinal and Lateral Driving				
	Cross Traffic Alert				Auto Pilot		
	All Driving						
	Surround View	Automatic Parking	Remote Parking	Valet Parking			
Parking							
Level 0	Level 1	Level 2	Level 3	Level 4	Level 5		
No Automation	Driver Assistance	Partial Automation	Conditional Automation	High Automation	Full Automation		
a human driver has control of all aspects of the dynamic driving task, even when enhanced by warning or intervention systems	a driver assistance system controls either a steering or acceleration/deceleration task with the human driver performing all remaining aspects of the dynamic driving task	a driver assistance system controls one or more steering and acceleration/deceleration tasks with the human driver performing all remaining aspects of the dynamic driving task	an automated driving system controls all aspects of the dynamic driving task with the human driver intervening when requested	an automated driving system controls all aspects of the dynamic driving task in specific scenarios	an automated driving system of all aspects of the dynamic driving task in all scenarios and environmental conditions		

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TATA MOTORS Connecting Aspirations



Why Autonomy?

- Societal benefits
 - Safety
 - Over 90% of accidents due to driver error
 - UK: 5 deaths per day, India: 400 deaths per day
 - Reuse road and parking congestion, air quality, parking
- Urbanisation







- Demographics
 - Car ownership mobility as a Service
 - More non-drivers e.g. elderly



Age Distribution of the World Population, 1980-2050

Sources:

UK World Urbanisation Prospects 2014 INRIX/Centre for Economics and Business Research Hiriko

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UK Autodrive Project

- Project objectives:
 - Demonstrate autonomous and connected vehicles (V2X) in real-world urban environments
 - Provide insight for stakeholders including legislators, insurers and investors
- Vehicles:
 - Pods (RDM) in Milton Keynes
 - Autonomous (TMETC and JLR)
 - Connected (TMETC, JLR and Ford)
- Duration
 - 3 Years: November 2015 October 2018
- Funding
 - Part funding from Innovate UK (around £10m of £19.2m)











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ROS/PTP/CAN







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TATA

Autonomous Software Architecture









Planning

Global Planner

 Finds the optimal route to the destination (according to some time/cost objective)



Behaviour Planner

 Static (strategic) behaviours from the map e.g. keep in lane, stop, give way, left turn



 Dynamic (tactical) behaviours in response to the environment e.g. traffic lights and objects (and evasive trajectories to mitigate risk)

Trajectory Planner

- Generate obstacle free paths
- Assign speed profiles



- Select trajectory
 - within lane boundaries, avoiding dynamic/stationary obstacles, comfortable (yaw rate; lateral and longitudinal acceleration and jerk; meets regulatory constraints (speed limits, stop lines, traffic lights etc.)
- Select evasive trajectory

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Control Options

- Pure Pursuit
 - Look ahead distance sets path intersection point
 - Steer wheels to match angle to intersection point
 - Accuracy/stability dependent on look ahead distance (include yaw damping)
- Lane Keeping
 - A quadratic equation approximates the path to be followed by the vehicle $X = xo + \theta Y + \frac{\rho}{2}Y^{2}$
 - Controller has three loops Position/Heading/Yaw rate loops speed scheduled gains
 - For lower speed higher curvature turns it was considered that accuracy would not be sufficient
 - Vehicle converges to an 'ideal path' so the ideal path and converging path need to be obstacle free
- Trajectory Tracking
 - More intuitive path creation starting at current position
 - Track a trajectory that has been already created to avoid of obstacles









Control Method

- Model Predictive Control
 - Inputs
 - Trajectory for a given time ahead
 - Dynamic model of the vehicle





- Outputs
 - Vehicle control sequence needed to track the trajectory by minimising a cost function for the given mode





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Control Implementation - Simulink







Control Method

- Model Predictive Control Design Considerations
 - Define 'prediction horizon' how far in time you are looking ahead
 - Define 'control horizon' how far in time you are predicting control for (control is then fixed for remainder of prediction horizon)
 - Optimal control sequence that could follow the trajectory is generated but all the control terms are discarded except the first one
 - Models:
 - MPC embedded
 - Model fidelity traded off against available online computational resources
 - Zero speed needs consideration (dynamic bicycle model is singular at zero speed)
 - Closed loop offline simulation
 - Complexity/fidelity versus simulation time
 - Delays old trajectories/old measurements as distributed processing and data transfer time delays (not fixed as non-real time network)
 - Measurement reference and conventions e.g. centre of gravity or rear axle
 - Linear analysis is complicated with non-linear components (particularly trajectories i.e. Bèzier curves) and time delays in the loop so guaranteeing stability control performance analytically is difficult





Time Issues

• Challenge

- Data ages from the disparate sources is needed
 - It is critical to use current up to date information
 - Delayed data needs to compensated for (and ideally the delays minimised) as
 - control loops are notoriously harder to stabilise and give accurate responses (larger errors and or lagged responses) when using delayed data
 - Ages needed to reduce errors in projecting states into the future (e.g. objects future position)
- Solution
 - Synchronise the different processors clocks Precision Time Protocol (PTP)
 - Time stamp data
- Results
 - Relative age of data is known but the ages variable (but are bounded)









Data Logging and Visualisation

• Requirements

- All on-road data is logged e.g. UK Department of Transport 'The Pathway to Driverless Cars: A Code of Practice for Testing'
- Playback visualisation for analysis/debugging
- Solutions
 - ROS and Speedgoat logging
 - Bespoke offline visualisation











Data Logging and Visualisation

- Enhancements
 - Online visualisation and logging capability





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Autonomous Hexa During Coventry and Milton Keynes Trials





Conclusion

- Pragmatic approach to Autonomous Vehicle Development
 - Off-the-shelf Tools
 - Linux/C++/Python/RViz/CANalyzer/MATLAB/Simulink
 - Off-the shelf hardware
 - Radar/LiDAR/GPS/IMU/cameras
 - Industrial PCs/Speedgoat/Drive-by-wire mobility solution
 - Bespoke third party software
 - Speedgoat bridge
 - Sensor Fusion
 - TMETC Software
 - Perception/planning/motion control
 - Sensor fusion
- Future Work
 - Third party and in-house tool enhancements
 - Lessons learnt to improve the system and develop it further towards higher autonomy levels
- Undergoing UK Autodrive Trials, Demonstrations and Dissemination in Coventry and Milton Keynes now (October 2018)





Finally

- Thank you
 - TMETC Maradona Rodrigues , Eliot Dixon, Lorenza Gianotta, Andy Harris, Johnathan Breddy, Jon Clark
 - MathWorks GianCarlo Pacitti
- Any questions?