Robotic Precision

In-Vehicle Robots, synchronised to GPS time and using feedback from Inertial Navigation systems can be used in multiple vehicles to repeat driving scenarios to an accuracy of 10 cm or better. Anthony Best Dynamics (ADB) and Oxford Technical Solutions (Ox TS) combine their expertise to enable repeatable Advanced Driver Assistance Systems (ADAS) tests in vehicles.

1 Introduction

Human drivers are good in steady-state conditions, such as driving down the motorway. By good here it is meant that a human can maintain a gap of 30 m to 40 m. For functionality testing of ADAS this is nowhere near good enough.

Change to dynamic conditions and ask a human driver to cut in front of another car at 35.4 km/h, at a distance of 12.5 m whilst braking at 0.1 G. Now they will struggle. Yet this is exactly the type of test that is required to test ADAS.

During benchmarking tests it would be unfair to compare systems unless you could manage to carry out the test with this type of repeatability.

Enter the era of robotic driving. The two company's have combined their expertise to deliver a synchronous robot.

The first in-vehicle robots performed path-following by controlling the steering alone. Driverless operation followed, with the path, accelerator and brake being controlled. The synchronous robot controls its path and speed based on time from an external clock. By being in the right place at the right time it is ideal for ADAS tests. Multi-vehicle tests can be performed by installing synchronous robots in each vehicle.

It is the accuracy of the robot though that makes it so impressive. In steady-state conditions the robot can position itself on the road within about 5 cm. While accelerating or braking the accuracy is less, mainly because the vehicle takes a long time to respond. In the data which follows the longitudinal accuracy is about 40 cm during speed changes.

Test repeatability is important when making decisions. Accidents can be considered as discrete events, you either have an accident or you do not. This is not a mathematically linear function. Since accidents are discrete an ADAS controller could change its operation suddenly. Imagine that at 5.1 m it does nothing; at 4.9 m it brakes hard. For this reason, repeatability during testing is essential.

At the moment there are no standards for the tests. After the tests have been designed though, it has to be possible to drive them. Here is where robots can help by driving far more consistently than humans can. Having repeatable driving allows people designing the tests to construct more realistic tests.

2 Fast Installation of Equipment

An important consideration is how long it takes to install the equipment, particularly when benchmarking several vehicles. ABD's In-Vehicle Robots are second to none and can be installed quickly and without any modifications to the vehicle. The In-Vehicle Robot, **Figure 1**, includes the following parts:

- steering actuator
- brake motor
- accelerator motor
- control electronics
- optional remote control station for driverless operation.

Even with the robot installed the vehicle can be driven normally. However the option for driverless operation allows potentially dangerous tests to be carried out without risk to the driver.

To enhance the In-Vehicle Robot so that it can follow predefined synchronous trajectories the Ox TS RT3000, an

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Figure 1: In-Vehicle Robot

Table: Numerical results showing the error and repeatability (stdev) for each of the tests as measured by Ox TS RT3000

Conditions	Lateral Error		Longitudinal Error	
	Mean (m)	Stdev (m)	Mean (m)	Stdev (m)
Steady-state	0.03	0.01	0.07	0.05
Pull-Out	0.07	0.01	0.07	0.05
Brake and Cut-In	0.04	0.01	0.3	0.2
Controlled Braking	0.01	0.01	0.08	0.03
Final Position	0.01	0.01	0.01	0.02

Inertial+GPS Navigation System, also needs to be installed. Typically the Navigation System is quickly installed on a pole or strut that wedges between the floor and the roof of the vehicle.

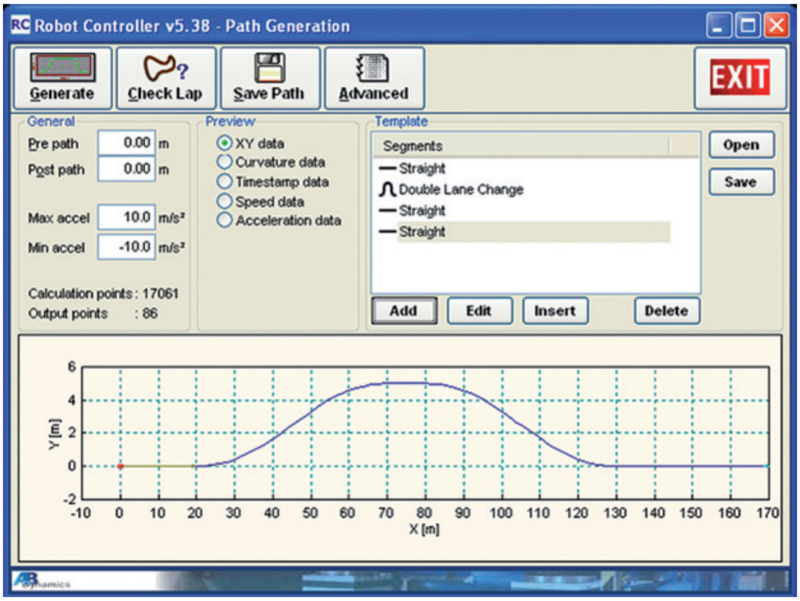
The System connects to the In-Vehicle Robot using Ethernet. It outputs measurements including position, velocity and time. Using this feedback, the In-Vehicle Robot is able to keep the vehicle on course at the right speed and at the right time.

When two (or more) vehicles are involved then the clocks on each vehicle must be synchronous. GPS provides a worldwide synchronous measure of time that is far more accurate than the millisecond precision required to synchronise moving vehicles. The time signal from each of the navigation systems is the same in all the vehicles.

Driving the vehicle is not everything. The Ox TS RT-Range system is a bolt-on addition to the Inertial+GPS Navigation Systems that measures the distances between the vehicles in real-time and outputs them to a CAN bus.

Using the RT-Range the full dynamics of both vehicles can be captured using one standard CAN based data acquisition system in one vehicle.

Wireless LAN is used to transmit the data from one vehicle to the other. Typically the Wireless LAN has a delay of 10 msec (one 100 Hz packet) and this only extends when the range is large. Wireless LAN operates reliably up to 200 m in open spaces and it is not uncommon for the range to extend to 700 m or more, depending on the environment.



Robot Controller v5.38 - Path Generation

General

Pre path 0.00 m

Post path 0.00 m

Max accel 10.0 m/s²

Min accel -10.0 m/s²

Calculation points : 17061

Output points : 86

Preview

● XY data

○ Curvature data

○ Timestamp data

○ Speed data

○ Acceleration data

Template

Segments

- Straight
- Double Lane Change
- Straight
- Straight

Figure 2: Path Generation Software makes it easy to generate the trajectory of the vehicles

3 Trajectory planning

An important part of the Robot is the trajectory planning software. ABD have invested heavily in software so-as to make the user interface easy to use yet flexible enough to cover ADAS tests.

The path generation software, **Figure 2**, contains a series of user configurable segments including lane changes, slaloms, curves, spirals and straights. The segments can be quickly pieced together to build almost any conceivable path. The speed or acceleration through any segment can be defined; because both the speed and trajectory are known a timestamp can be calculated for each waypoint.

The expected lateral and longitudinal accelerations can be reviewed to check that they remain within the vehicle's capability. Collision avoidance software plays out the path of the two vehicles. This gives a visual check that the two vehicles do not collide. Before the start of each test the user enters the GPS time for the test. The robot does the rest, guiding and controlling the vehicle to be at the right position at the right time. The test can be repeated time and time again giving exceptionally repeatable performance.

4 Real-World Performance

A single test that aims to show different aspects of synchronous control between two robot controlled vehicles has been used. The test, illustrated in **Figure 3**, is 1 km long with the longitudinal and lateral distance between the vehicles controlled throughout.

At the start of the test is a steady-state section with both vehicles travelling at constant speeds. The blue vehicle is travelling at 72 km/h whereas the red vehicle is faster, at 90 km/h. The second section shows the pull-out for an overtaking manoeuvre where the red vehicle overtakes the blue. Third is a cut-in with braking. The red vehicle brakes, slowing down to 72 km/h to match the speed of the blue car, and then cuts in-front. Finally both vehicles come to rest side by side with the braking controlled so that the vehicles stop at a predefined position.

Figure 4 shows the results for ten runs. These graphs show the measured error compared to an ideal test. The Table shows the results numerically for each section. The lateral error is always small, with slight peaks where either vehicle changes lane. Lateral error is controlled by the steering, which is generally very good on all vehicles. The longitudinal error is far more difficult to control. In contrast to steering and lateral control the vehicle response in terms of braking and accelerating has significant delays. Non-linearity is also a problem as there is a big difference in the control available during braking compared to accelerating. In addition the acceleration response changes with engine speed and vehicle speed. All these factors make controlling the longitudinal distance more difficult.

In spite of these difficulties, the longitudinal error in the steady-state is very good, with the vehicle maintaining less than 5 cm 1 σ variation.

During the speed changes the longitudinal error grows, with mean errors less than 30 cm and variation around 20 cm 1 σ.

Finally the braking to a single point shows excellent longitudinal control with the mean error less than 10 cm and the variation less than 5 cm 1 σ.

At the end of the test the two vehicles stop consistently within 3 cm of their target position.

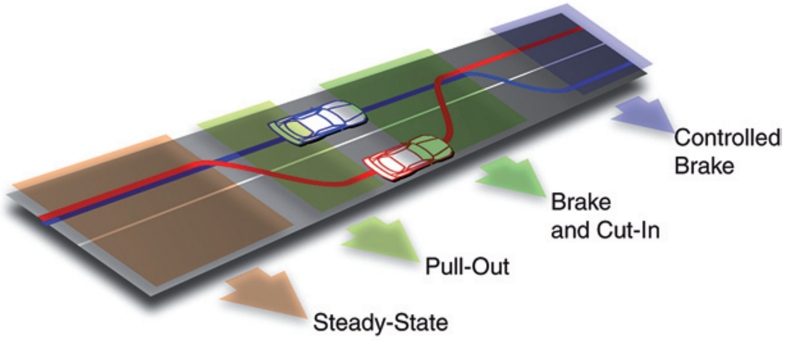


Figure 3: Planned path of the two vehicles with the red vehicle overtaking the blue. The sections of the test are highlighted

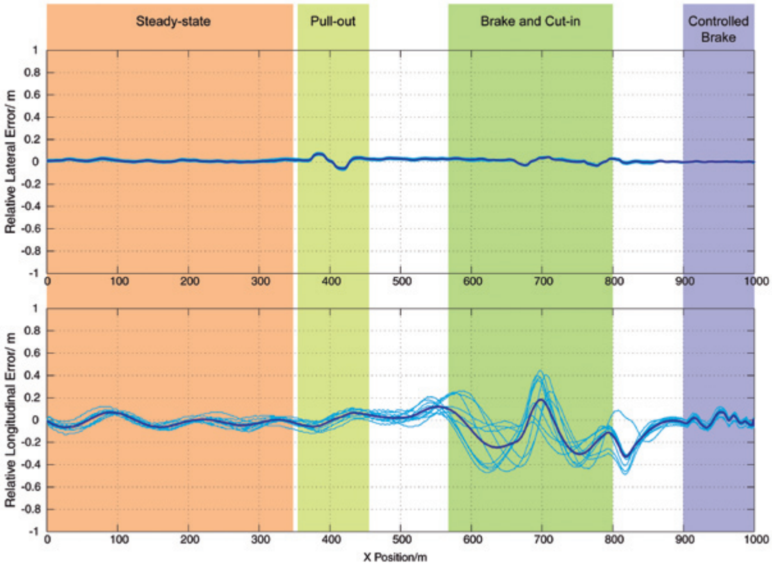


Figure 4: Lateral and Longitudinal error between vehicles compared to the programmed position. 10 runs are shown along with the mean data

5 Conclusions

Robotic driving provides an excellent mechanism for testing ADAS because it is repeatable and controllable. The system can be installed quickly in virtually any vehicle, making it suitable for both long term development and benchmarking tests. All forms of tests can be carried out, including overtaking, cut-in, intersection scenarios, blind spot detection, lane departure warning, etc. Adaptive cruise control (ACC) requires several vehicles to be accurately controlled in order to truly understand or test the decisions being made by the system. Robotic systems are ideal for this. The repeatability and system accuracy is much better than human drivers can achieve, making testing easier, quicker and more reliable. ■