Innovation briefing

Move over LiDAR, mmWave radar is here

The case for simulation – and specifically mmWave radar simulation – to reduce the cost of autonomous vehicle development

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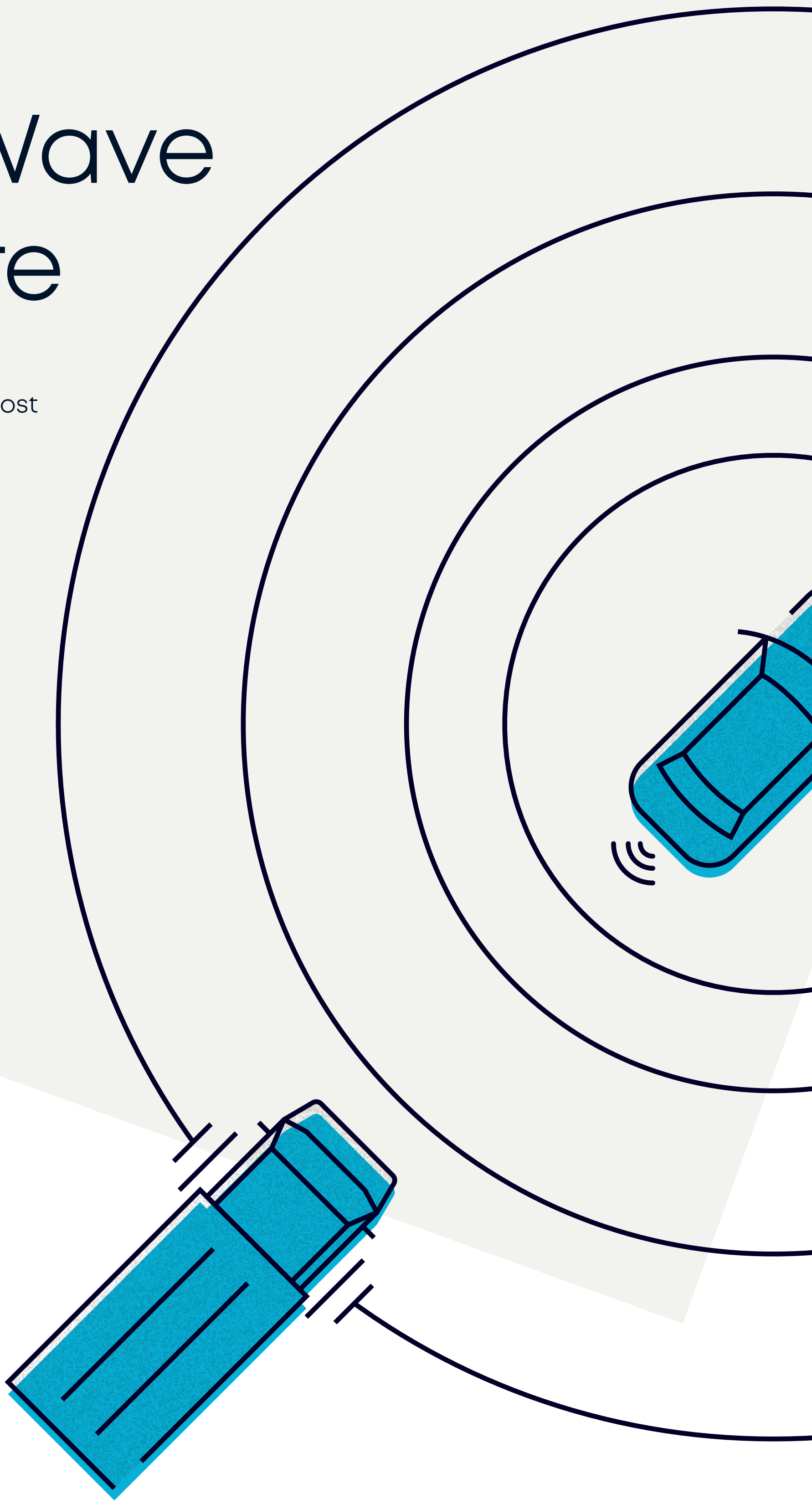

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CC in three your key notes to take away

1. Multiple industries are increasingly frustrated by the prohibitive cost and excessive timeframes of obtaining real-world data for autonomous vehicle (AV) development

2. Using simulated environments to train machine learning models slashes the need for real-world data collection and provides a platform for rare use cases

3. mmWave radar represents a commercially viable addition to LiDAR, cameras and GPS for AV guidance – speeding up and cutting development costs of a sensing array

What this briefing reveals

We'll explore the benefits of using radar simulation to speed up, add confidence in and cut development costs of a radar sensing array. The briefing will reveal the suitability of mmWave radar simulation for the unusual use cases where camera-based guidance fails – low light, snow, fog and so on – without having to wait for those conditions to occur naturally.

This technology unlocks reduced autonomous machine costs and greater levels of autonomy. Its ability to handle wider use cases pushes it towards Level 4 and possible Level 5 in the future.

Why mmWave radar is now a vital part of the AV technology stack

A wide range of industries across the world have come to the same conclusion. Autonomous systems are now crucial for commercial recovery and prosperity as businesses reel from labour shortages and changes in habits exacerbated by pandemic restrictions.

But all agree that vital progress too slow. This is particularly so in autonomous vehicle development, which is hampered by the time and cost of collecting the millions upon millions of driving hours required to train systems. Simulated environments offer a solution – dramatically reducing the need for real-world data collections and providing a platform to test rate 'what if' use cases.

The key to success – for everyone from automotive OEMs to construction equipment vendors – will be in unlocking cost-effective AV guidance. But LiDAR is expensive and camera-based systems are susceptible to failure and interference from the likes of dust, dirt and fog. GPS is susceptible to scintillation (interference caused by solar flares) – so carries the added cost of reliable supplementary ground-based localisation technologies.

We believe mmWave (millimetre wave) radar offers the solution. Indeed, we say it is the key sensor for the future of AV because:

- It's very flexible – detecting objects at long range and offering great resolution at short range in addition to giving relative speed
- Radar shines where camera and LiDAR sensors struggle – in poor visibility for example
- Cost advantages over cameras allows deployment at a lower cost point
- Radar doesn't entirely replace other sensors but is an additional component that improves overall accuracy and lowers costs

The issues and challenges of current technology

Radar is the hardest sensor to simulate, but why is this so? Let's look at the very high speed of physical phenomena being observed. Camera sensors sample at a maximum of 60Hz, LiDAR 150kHz (150,000 pulses per second) while radar is 40MHz. EMF (electromagnetic fields) and continuous wave characteristic of a radar adds complexity when it comes to modelling the world.

In addition, radar simulation needs to deal with complex interdependence and interactions between objects in a scene – a wave is subject to multiple distorting bounces within the scene before it arrives back at the sensor to be interpreted. Also, many compromises have to be made within the simulation event time frame for object detection and tracking (because of the wide range of timeframes involved, from nanosecond granularity of the GHz waveform, to 10s of milliseconds for observable changes in the scene).

Sensor tech is automotive focused, off-highway markets are neglected

Economics have dictated that sensor manufacturers have focused their efforts on serving the clients with the greatest product volume needs – automotive OEMs. But the opportunities for off-highway applications such as construction, agriculture and mining are arguably greater and debatably easier technically.

However, these industries demand slightly different sensor stack performance and have operational environments markedly different to a highway or city centre. Simulation is required to define performance in these new use cases and determine how modified radar units will perform.

Modelling off-the-shelf radar units in a simulated environment

If performance of off-the-shelf radar units can be modelled in a simulated environment to a high degree of accuracy, that data can inform new signal processing techniques and antenna design to achieve the desired performance. Achieving this without simulation would be prohibitively expensive and time consuming, largely due to the need for extensive data collection.

What are the benefits of simulation?

The use of simulation is becoming a critical part of system development. Autonomous driving is leading the way, but other markets are seeing the potential of:

- Improved development speed
- Reduced costs
- Testing use cases that are not possible in real-world testing
- Perfectly repeatable tests greatly facilitate evaluation of changes

The challenge is how to reduce supply chain risk by validating algorithms with different radar sensors. Radar simulation must be able to account for radar differences to be representative and allow validating algorithms based on different sensors. It is possible to show algorithm performance equivalence and differences if the radar characteristics are modelled accurately.

Modelling radar details is also important to showcase how one radar may be better than another. As we've already said, current simulation environments are targeted to automotive industry with little or no coverage of other user cases.

Introducing our simulation framework

CC has developed a simulation framework allowing the development of arbitrary simulation environment that can be used to develop sensor, algorithms (AI or non-AI) or full ADAS (advanced driver assistance systems).

A look at measurement (the how)

Initially, we need to know the goal of the radar simulation. At a very low level, do we want to simulate the inputs to the ADC (analogue to digital converter) to reuse most of the radar software directly in quasi SIL (software in the loop) simulation? One level higher, do we want to model the ADC input to generate range profiles and use these simulated range profile as inputs to the rest of the system? Even higher, we can model point detection and use these detections to simulate object detection and tracking.

Because of the time frame of the observed phenomena and the fundamental behaviour of a radar wave behaviour, the development of the simulator is an exercise in compromises. We can't simulate a continuous wave, so instead we use a ray casting technique to sample and discretise the world as seen by the radar. The more rays, the better the accuracy but also the higher the computational load.

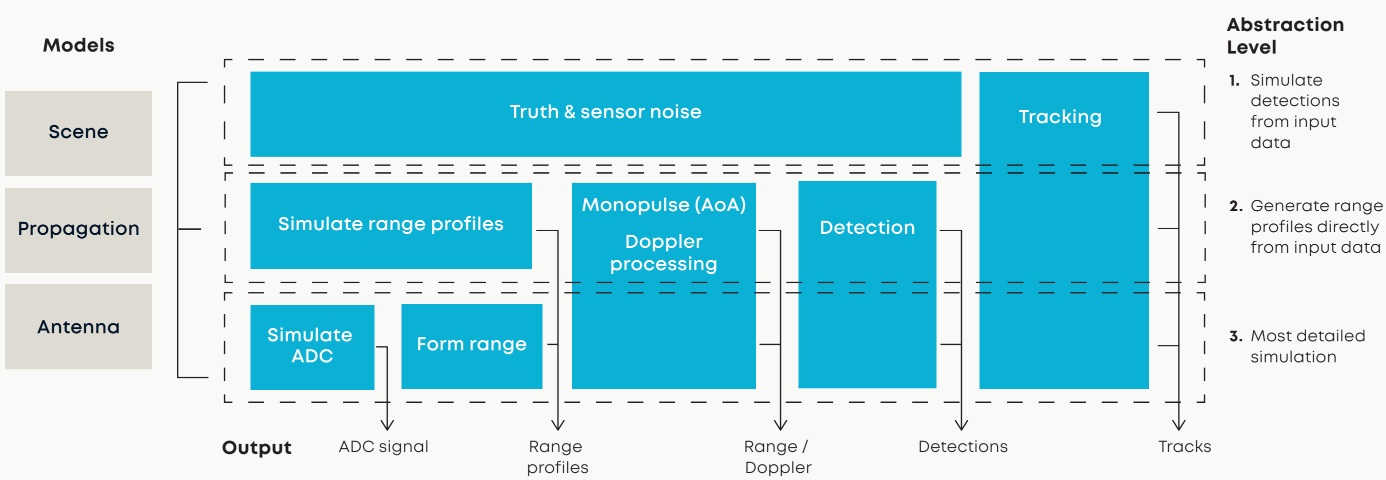
The simulation updates the state of the objects at a fixed time interval (usually 20 milliseconds in game engines). This is an eternity for the radar simulation which creates discontinuities and introduce errors. The simulation must extrapolate additional data in between simulator updates. Some of the extrapolation will end up being wrong so the question of how to handle those cases is a tricky one.

Interaction between a complex object and the radar wave is also very complex and can't be simulated quickly. So, objects are replaced with simpler equivalent models that allow simplifications. But achieving an accurate model of a target is difficult. It depends on how far the target is from the radar since the relative size of the target with respect to the radar wavelength plays a huge role on how it is seen by the radar. So, using the correct model for the correct situation is very important.

Having executed all these simplifications, the simulation will still involve a large amount of computation. So, we must investigate speed-up strategies. Fortunately, a lot of the computations are vectorizable and parallelisable so we can use GPUs to hasten the process.

Abstraction levels in radar simulation

There are a range of abstraction levels which can be used. The most detailed is the bottom channel and includes ADC simulation for generating range profiles. The middle option is to generate the range profiles directly from the input data (provided by the game engine). The most basic level of abstraction takes the input data and simulates detections (i.e., points where the radar would signal the presence of an object), detection however is only valid for a short period of time and can be erratic (with many false detections).



Focusing on the right approach

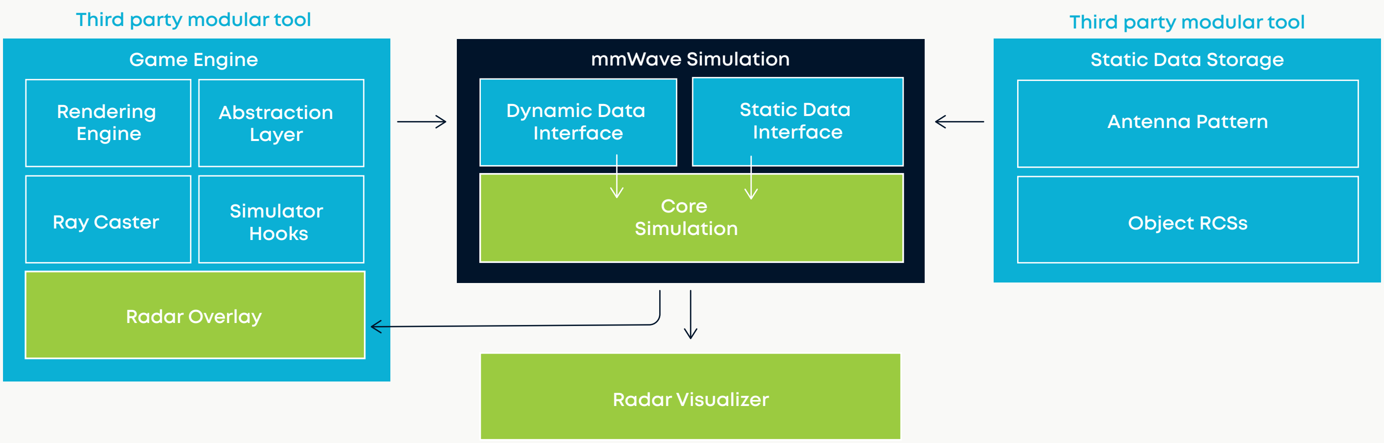
The desired approach is to create a modular simulation with well-defined interfaces between each stage.

Stages can be replaced independently to vary the level of details or be customised for particular radar. Additional front-end stages can be added to generate inputs at a lower abstraction level giving even more detailed simulation where required without impacting performance when the level of detail is not required.

We can interface with different input generation front-end or processing back-end by customising a single stage or the simulation. This avoids vendor lock-in. The back-end processing stage can be replaced by an actual radar processing algorithm for added fidelity – one step towards SIL testing.

The development was based on the Unity game engine simulation environment. Here, generating inputs at the desired level of accuracy creates its own challenges. Game frame rate is only 50 Hz which is much too slow for radar, so state interpolation is required between samples.

mmWave radar simulation architecture



With the dynamic data interface (top left) and the static data interface (top right) we can keep the core of the simulation separated and isolated. This means we can use any game engine or precomputed simulation with the system.

Something to consider...

Game engine physics models usually run no faster than the frame rate (up to a minimum amount). Ideally the physics simulation would be able to be decoupled from the frame rate and run at a higher frequency to achieve better simulation.

Our next steps to improve performance

Our current framework is only the start of a full-fledged radar simulation. The next areas for accuracy, noise reduction and tracking improvement are:

- Equivalency. Do the results correlate to the real world?
- Multi-path. Currently reflections are not taken into account – a big issue for radar
- Settings. The need to address problematic radar environments such as foliage
- Ghosts. In some cases, ghost targets are created which behave exactly like a real target and are very difficult to eliminate.

Why CC?

At Cambridge Consultants, we believe in a future unconstrained by current thinking. By challenging conventional approaches, we help our clients to achieve transformational change. We can draw on deep expertise to offer a uniquely broad response to you automation needs. Our skills and knowledge combine with real-world application experience that has been earned by multidisciplinary in-house teams.

Above all, we love to create collaborative partnerships with our clients, and are proud of our record of developing and maintaining long-lasting, mutually beneficial relationships. The team is ready to help get you where you want to be – with reduced development risk, time and cost.

Let’s continue the conversation

We hope you’ve found value in this CC Innovation Briefing on using simulation to model mmWave radar for autonomous vehicles. Please get in touch to discuss your ambitions.

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