DETECT & AVOID TECHNOLOGY FOR eVTOL
Revolutionizing Urban Mobility
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Executive Summary

The future of travel will be transformed by electric Vertical Take-off and Landing (eVTOL) aircraft. With cities being overburdened and infrastructure unable to keep up, there is an urgent need for a revolutionary solution to take on urban woes.

eVTOL has the power to rid cities of traffic and environmental challenges. Self-piloting will be key to mass adoption of eVTOL aircraft. The technology that will make it all possible is Detect & Avoid. The ability to sense and avoid objects in the flight path, navigating through birds and other objects in the air and on land.

Bosch's Detect & Avoid technology, ‘DeepSense’ ©, has the capability to ensure that the aircraft is able to analyze, understand, and interact with its environment, while boosting safety and efficiency. Bosch Detect & Avoid would be critical in terms of safety and overall operational efficiency for future urban mobility and autonomous operations.

This white paper talks about the need for eVTOL vehicles, the challenges faced, and how a path-breaking technology such as Detect & Avoid can reinvent urban mobility.
Introduction

It is a typical morning. Judy and Elroy are getting ready for school. Jane is prepping breakfast for her kids and her husband George. Rosie, the robotic maid, is cleaning the house. After goofing around with the kids and gulping down his breakfast, George gets in his aerocar and flies off to work.

Wondering if you are reading the script of the 1962 animated sci-fi sitcom ‘The Jetsons’? It is no longer science fiction, as zipping to work in an ‘aerocar’ will soon become a reality! In the last one year many companies have announced innovations and advancements in their work in eVTOL aircraft. Does this mean that daily travel as we know it is going to be revolutionized completely? The answer is a resounding ‘Yes’.

A smooth, safe, secure and efficient ecosystem that supports human travel on eVTOL aircraft or automated flying drone taxis requires an underlying layer of a sensor system that becomes the ‘eyes’ and the ‘brain’ of the aircraft. Bosch’s Detect & Avoid is an example of an intelligent system that will drive the technology for autonomous eVTOL aircraft in the near future.

The Need for eVTOL Aircraft

Take the example of Mumbai, one of the world’s fastest growing cities, with a vast population. The city’s transportation infrastructure is bursting at the seams; high vehicular traffic throughout the day has impacted the Air Quality Index (and pollution) to an alarming level. Travel by road during peak hours can be a nightmare. All this makes an excellent case for a newer mode of transport like eVTOL.

Let’s look at some numbers first. The world’s cities are home to 54 percent of the earth’s total population. By 2050, this number is projected to increase to 66 percent. Ninety percent of the urban increase is expected to take place in Asia and Africa.
The reason is undoubtedly mass urbanization, which is highly unsustainable, according to a recent UN report. The challenge of providing basic services and infrastructure is crucial for sustainable urbanization. Current transport infrastructure such as Mass Rapid Transport systems, trains, buses, and flyovers are saturated, and building new ones takes years and requires massive investments. Alternatives such as hovercraft, hyperloop – or, for that matter, choppers – are beset with challenges. Hovercraft have limited capacity and cannot be operated during the monsoon season. The hyperloop project will incur huge infrastructure cost, as well as clearances of existing settlements and redevelopment of land. As for helicopters, there is a scarcity of trained active pilots, and this mode of travel is expensive and inefficient.

eVTOL aircraft is the solution to these bottlenecks. Not only can they resolve traffic woes, they can do so in an environment-friendly way. Let’s take an in-depth look at how eVTOL can solve the current challenges in urban mobility.

**Tackling the challenge of urban mobility**

- The transportation alternatives mentioned above do not fully address the problems arising out of rapid urban growth. There is a need for a mobility solution that tackles concerns such as cost, time, pollution, dwindling land space, and mind-numbing traffic.

- Experts believe that personal air mobility and ride sharing is the answer.

- One can expect to see the launch of electric aircraft and other eVTOL aircraft soon; many industry stalwarts and newcomers are already beginning to explore this opportunity.

- Coming to environmental concerns, a fully electric system means there will be no CO\(_2\) emission. Also, Distributed Electric Propulsion (DEP) will address any safety issues.

**How will eVTOL work in the real world?**

- How will this new mode of transportation scale? Piloting isn’t a common skill. The concept of self-piloting will bring about a major push in the adoption of eVTOL aircraft.

- A self-piloted system should be capable of taking on many of the tasks assigned to the pilot, including sensing and avoiding objects in the flight path.

- The system has to ensure that the aircraft is able to analyze, understand, and interact with its environment during takeoff, cruise and while landing. It must also ensure the safety of passengers and other flying vehicles nearby. Additionally, it should be able to function accurately in all weather conditions and Degraded Visual Environments (DVE).

These features are provided by Bosch’s Detect & Avoid technology, DeepSense. Bosch’s DeepSense will empower automated flying in eVTOL aircraft for maximum safety and efficiency. With advanced machine learning and Artificial Intelligence (AI), the system will have enhanced capability for better sensing and decision-making. Here’s how we envision the most secure and reliable system to fly with.
Bosch’s detect, sense and avoid system currently consists of Radar, Camera, LIDAR and IR sensors and has a capability to augment with other sensor inputs in the future. This intelligent system will scan the environment to detect objects, predict their intentions, and rely on an intelligent algorithm to avoid hitting the said objects. This is an all-weather system that can ‘see’ through dense fog, cloud, rain, and darkness (where camera performance is drastically compromised). By using triangulation based on inputs from at least 3 sensors at a time, one is able to detect the position and velocity of the targets and classify the type of object accurately. Additionally, this system is capable to broadcast and receive ‘keepalive’ signals with position, altitude and UIN (Unique Identification Number). This will reinforce the system for calculation of intruder’s trajectory.

Current Detect & Avoid systems are mostly vision-based, which limits the use of eVTOL to clear weather and daytime usage only. Moreover, the range is typically up to 500 m. The new radar technology being developed at Bosch will scale up the range to 1-1.5 km. Further, the radar design provides a 3D, 360° field of view with strategically mounted sensors to minimize blind spots around the host drone. Work is on towards achieving 360° coverage using an electronic phase steering radar made of linear and planar arrays.

Bosch applies deep reinforcement learning for forming long-range sensing strategies. Each Detect & Avoid sensor has analytics built on top of it.

There are two major challenges that make autonomous flying different from other robotic tasks. One is ensuring functional safety – something that machine learning has difficulty with. In these multi-agent settings, each sensor with its analytics will act as an active agent, adopting cooperative learning paradigms between them. As a result, a complete sensing network will evolve as a fully functional collaborative framework with higher redundancy, safety, and stability.

The second challenge is the unavailability of very long-range sensors in the industry. Considering the speed of eVTOL and that of other flying objects in airspace, it seems that a minimum detection range of around 1 km will be required.
Empowering the system with AI and Deep Learning

Bosch’s deep learning algorithms further enhance the capability to detect and classify objects, both on the ground and in the sky. One algorithm that pushes performance boundaries is semantic segmentation. This not only classifies objects on a broader level but also classifies each pixel in the image and associates it with a certain type of object.

![Multi-Threat Tracking By Radar Vision System](image1)

**FIGURE 3: Multi-Threat Tracking By Radar Vision System**

![Semantic Segmentation For Take-off and Landing Scenarios](image2)

**FIGURE 4: Semantic Segmentation For Take-off and Landing Scenarios**

Radar system with built-in analytics

Radar can detect diverse targets with different radar cross-sections. Bosch is building radar analytics on top of radar time and frequency domain data to detect and classify moving targets using Deep Neural Nets. This will help autonomous agents to not only detect but also classify threats, helping the ‘Avoid’ section to prioritize collision avoidance. This radar can ‘see’ up to a distance of 1-1.5 km with elevation and azimuth Direction of Arrival (DoA) information with threats classified. This can also help the system to avoid false detection or inaccurate judgement.

Top-of-the-line hardware and software solutions

Coming to hardware, Bosch uses military-grade radar hardware that has a small form factor, keeping power consumption and weight constraints for flights in mind. The hardware is capable of processing the multi-sensor data in real time and creating an object map in 3D space. The object map can interface with flight control to plan the avoidance strategy.
The software will initially be built for pilot advisory mode, i.e. threats and objects will be classified, labeled, and tracked, and the same information will be displayed on the human machine interface mounted inside the cabin. Going forward, in collaboration with eVTOL manufacturers, Bosch plans to scale up to autonomous flying capability.

DeepSense Architecture

The collision avoidance system designed by Bosch works on two distinct but collaborating modes as depicted in Figure 5.

The first element is the cooperative mode, where information interchange occurs between aircraft and ground control systems through transponders. However, non-cooperative targets are not equipped with transponders, and this necessitates collision avoidance with an onboard Detect & Avoid solution.

Bosch’s vision is to evolve a non-cooperative mode of collision avoidance so powerful that full autonomous flights can be made possible.

Functional Blocks of Detect & Avoid

The developed architecture is shown in Figure 6, where different functional blocks of Detect & Avoid can complement one another. Currently, the cooperative mode is predominant but it relies heavily on the communication links and supporting infrastructure. In future, we can expect an on-board system that is accurate and reliable enough to augment the cooperative mode.
As it is evident from the name, there are two primary bricks (or blocks) in the entire system. The Sense brick uses data acquired from the various sensors, collates them in a common reference coordinate, creates a comprehensive 360° view of the surroundings, identifies and creates a list of potential threats, and prioritizes them. The Avoid (or Action) brick, based on inputs provided by the Sense brick, determines the action. This consists of giving commands to the flight controller to negotiate the threat, alter the flight plan, or ignore if required.

The overall Detect & Avoid system will have a multi-core CPU and GPU-based rugged hardware with interfaces to the sensors and HMI display through MIL-grade connectors. The HMI Display will be a synthetic vision system, where all the threats in 360° are presented to the pilot for visualization in Advisory mode. Once the algorithm matures, it will be possible to use it for completely autonomous flights where the role of HMI display is limited for calibration and maintenance. When the flying mode goes fully autonomous, Detect & Avoid will issue commands to the flight controller.
AI and Certification in the Avionics Industry

In the Bosch Detect & Avoid system, there are two areas where attention needs to be paid to certification:

1. Use of multi-core CPU and GPU


Tremendous efforts are going on in the industry to certify both. Currently, no standard has been established, but various groups and forums are working towards it. The advantages of using AI and multi-core, especially considering the recent advancement of AI in autonomous driving and flying, are manifold, but the need for uniform safety standards is critical for the success of commercial eVTOLs.

Bosch plans to implement Detect & Avoid technology based on multiple partitions to address the current gaps in certifiability of AI and multi-core. As the eVTOL industry moves from a piloted phase to a fully autonomous phase in the future, one would need to figure out how to certify the hardware and software at higher safety criticality levels.

Conclusion

There is tremendous potential for eVTOL urban air mobility as it will save time, reduce congestion on roads, lead to a cleaner environment, and save time for commuters. Deep learning and recent developments in GPU and high-speed digital sensor processor boards are bridging the gap between human vision and machine vision to enable eVTOL aircraft to fly with ease, safety, and efficiency. We see the convergence of the automotive and aerospace industry and Bosch is well-positioned to lead this emerging trend. Bosch’s Detect & Avoid aims to play a pivotal role in driving the future where eVTOL aircraft will become mainstream. An integrated ecosystem of partners should bring the cost down through economies of scale or government subsidies, and we can soon be living our sci-fi dreams. To see this dream turn to reality, Bosch India is leading the innovation in Detect & Avoid technology, leveraging competency in deep learning and sensor design expertise.
About the Authors

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With a PhD in Deep Learning Optimization Technique, Gourav is the originator of the idea of **DeepSense**. **DeepSense** is the Deep Reinforcement Learning-based Detect & Avoid technology. Gourav spearheads the direction of technology in the niche field of Autonomous Systems for a safer flying ecosystem for Pax Drones and eVTOL.

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With strong product management skills, Dileep leads a team of engineers and researchers to bring the idea of Detect & Avoid to reality. Agile Project Management, System Integration, Innovation Management are his key areas of strength.

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Hariprasad is a business leader and intrapreneur with strong product and innovation background in urban mobility domains such as Aerospace, Automotive and Rail Transport. He is a thought leader with a vision to transform urban mobility. Urban mobility convergence, which brings Automotive and Aerospace together, is one of his key areas of focus.