4D IMAGING RADAR

Providing Real Ego-Velocity Precision

EGO-VELOCITY PRECISION

While ego-velocity can be estimated using a variety of methods, only Imaging Radar provides the precision and continuity required for true autonomous driving.

An accurate estimate of a vehicle's own velocity, referred to as ego-velocity, is crucial for truly safe ADAS and, eventually, autonomous driving. Advanced radar imaging deciphers the car's own speed, leveraging its ability to sense the environment in high resolution specifically in elevation, and its ability to detect stationary objects.

EGO VELOCITY & AUTONOMOUS DRIVING

To achieve true safety, a vehicle must have a coherent understanding of its environment. One of the greatest challenges to achieving this understanding is being able to map the vehicle's surroundings while simultaneously localizing it within that map as it is being continuously generated. This challenge is addressed by SLAM, Simultaneous Localization And Mapping.

DISTINGUISHING BETWEEN STATIONARY AND MOVING OBJECTS

A key element of SLAM is being able to distinguish between stationary and moving objects in the vehicle's environment. Since the speed of objects in a moving environment is relative, a vehicle must be able to understand whether an object is moving toward it because the object is moving or because the vehicle is moving, or both. Making this distinction requires the ability to accurately determine the vehicle's ego-velocity. By accurately estimating and then deducting ego-velocity from the perceived velocity of environmental objects, the vehicle is able to decipher which objects are stationary versus which are moving while the vehicle itself is in motion.

ENABLING THE "SIMULTANEOUS" OF SLAM

The "simultaneous" part of SLAM refers to the ongoing process of generating a map that is improved by data gathered when the vehicle moves on it, while analysis of how the vehicle moves is enhanced by the continuously improving accuracy of the map itself. Each of these two inseparable actions relies heavily on accurate estimation of ego-velocity. It is impossible to deduce how the vehicle is moving within the map without an appropriately precise estimation of ego-velocity. Likewise, the accuracy of the map itself requires the correct assessment of the speed of all objects on it, which also cannot be deduced without trustworthy ego-velocity.

Environmental awareness and comprehension is fundamental to vehicle navigation, whether performed by man or machine. While human drivers are somewhat aware of their own limitations and usually take large margins to compensate, in the autonomous car it is the role of sensors to provide this added safety. Having a good estimate of ego-velocity, thus, is a crucial task for autonomous driving.

METHODS OF ESTIMATING EGO-VELOCITY

Vehicle sensors currently on the market have each tackled the problem of ego-velocity based on their own strengths, but each also suffers from significant disadvantages.

- **Speedometer** (from car's own OBD): While on-board speed measurement by the car is always available, relying on the RPM experienced by the car's own wheels to yield the ego-velocity measurement is prone to high inaccuracies, as it can vary depending on tyre inflation, tyre heading with respect to the car's body, and the differential-unit installed between the wheels. A natural extension to the OBD speedometer is to fuse it with acceleration (and yaw rate) as measured by an external IMU sensor. Such fusion can alleviate the innate inaccuracies in the OBD's speedometer, but relying solely on this method to track ego-velocity is still not robust enough, since velocity measurement by the OBD speedometer suffers from systematic biases, and not only from random noise.

- **GPS:** Using Global Positioning System for ego velocity estimation suffers from two significant drawbacks that prevent it from being responsible for ego-velocity estimation in an autonomous vehicle. First and foremost is its low accuracy and thresholding (cutoff) behavior at low velocities (around 0 km/h), which is the case in slow traffic and traffic jams. The use of high-end GPS units can potentially push the cutoff to a lower number, but such high end sets are expensive, and still show the undesirable cutoff, even if at lower velocities. The other obvious disadvantage of GPS for ego-velocity tracking is that GPS reception can be problematic, yielding a "not-available" response from the GPS set, or even worse, measurements that disguise themselves as being reliable, but in fact rely on partial or no reception.

- **Camera and LiDAR:** Optical sensors typically cannot measure velocity directly, and have to rely on integration of multiple frames.

- **Traditional radars:** radars on the market today lack the ability to accurately detect stationary objects. Therefore they are not effective solutions for ego velocity measurements.

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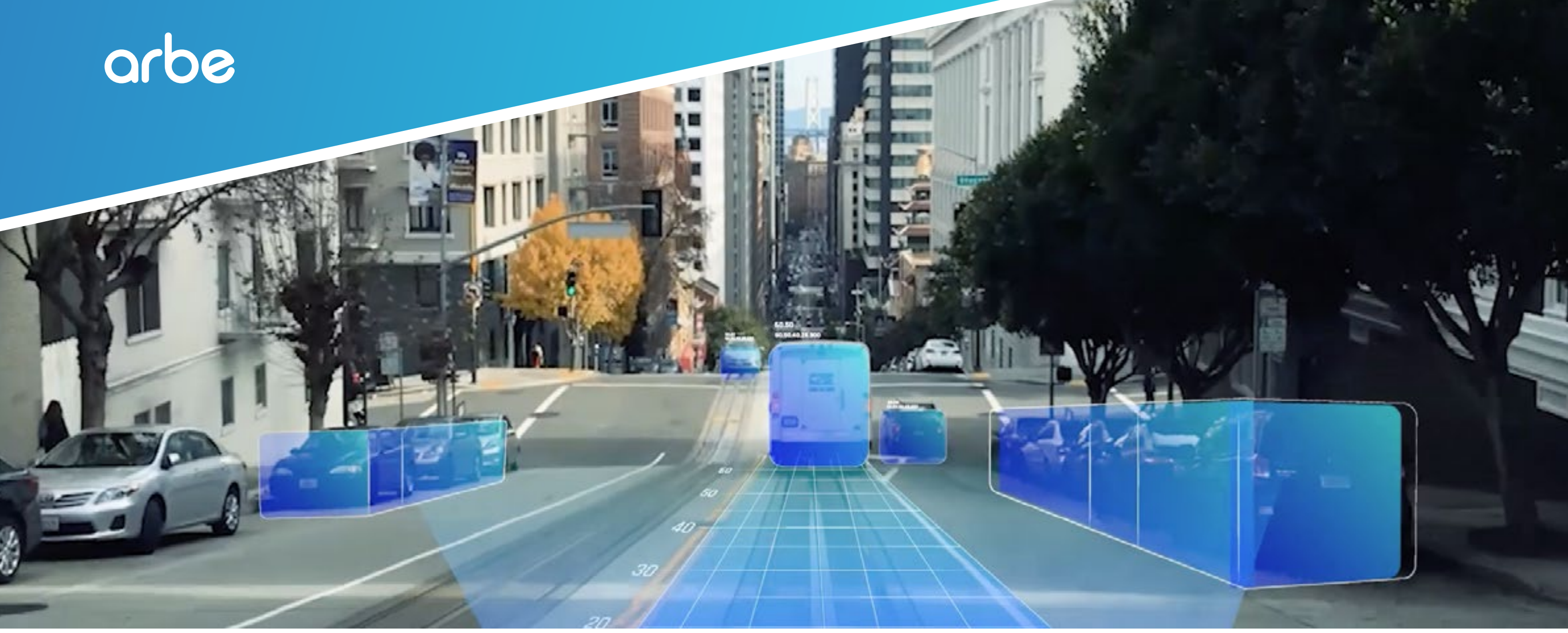
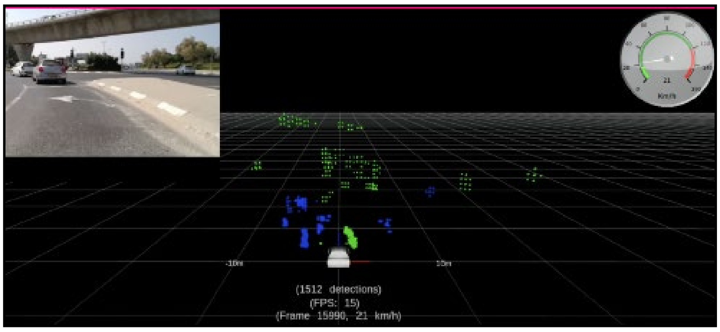
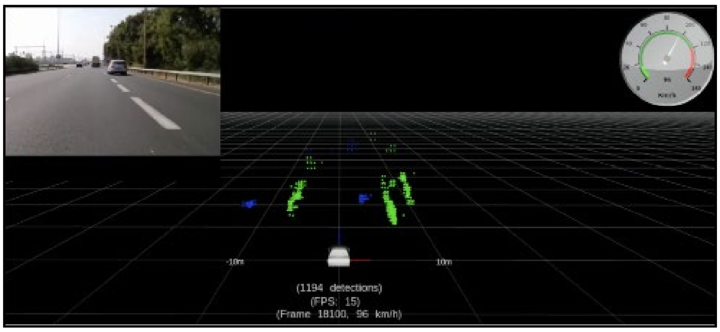


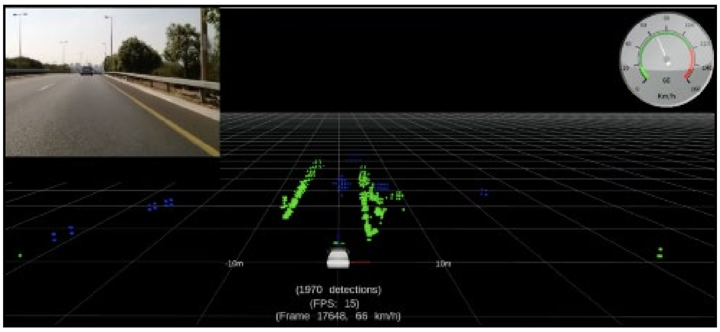
IMAGING RADAR'S CLEAR ADVANTAGE

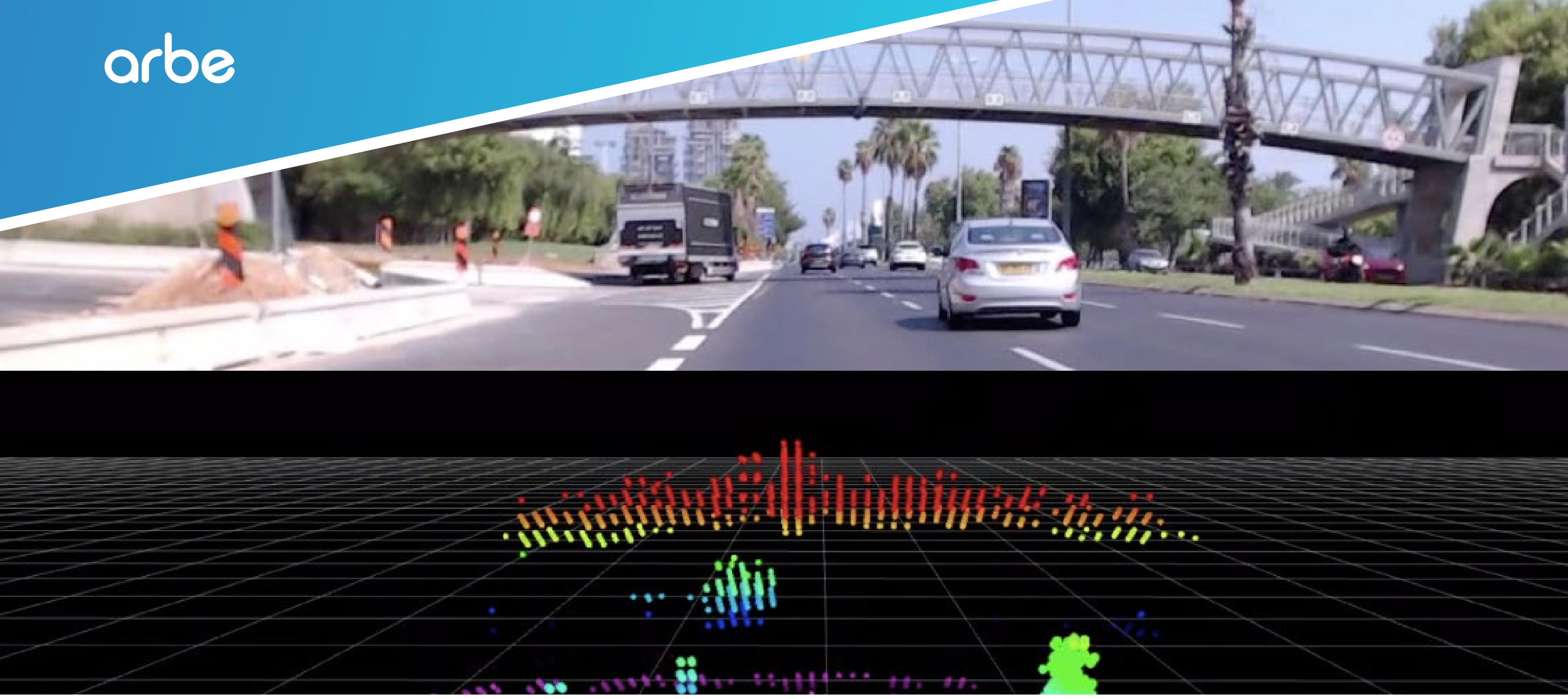
By contrast, based on its ability to distinguish between radar detections that stem from stationary objects and those that stem from dynamic objects, and by exploiting its high resolution in all dimensions (range, azimuth, elevation, and doppler), an Imaging Radar can make a highly accurate, per-frame, ego-velocity estimation, that is continuous (no thresholding behavior) around 0 km/h, and can overcome problematic scenarios such as bridges, tunnels, traffic jams, and garages. Thus, while ego-velocity can be estimated using a variety of methods, only Imaging Radar provides the precision and continuity required for true autonomous driving.

EGO VELOCITY TAKEN BY RADAR:







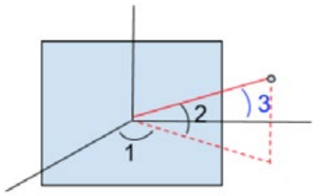


THE ROLE OF ELEVATION RESOLUTION

To understand the importance of elevation to the process of ego-velocity tracking, let's assume that the radar-car is driving "forward" at a constant speed of ***v***, and consider a single radar detection at range ***r***, azimuth ϕ (bore-sight is ϕ=0), and elevation θ (again θ=0 is bore-sight) with respect to the radar, whose measured line-of-sight (Doppler) velocity is v_r. Up to measurement noise, then, one can extract the desired ego-velocity from the geometrical relation

$$v_r = v \cos\theta \cos\phi$$

as seen in the figure below, where the antenna is shown as the light blue rectangle, ϕ is the angle 1, and θ is the angle 2



Having no access to elevation (as is the case in traditional radars) has two important implications for the ability to calculate ego-velocity. The first implication is that one is forced to discard the portion of elevation in the relation (assume that θ=0). The other, more subtle, implication stems from the fact that for planar antenna (which is the case with all traditional radars), the azimuth angle ϕ is in fact inaccessible to the radar. Instead, one can only measure the angle between the antenna's "horizontal axis" and the line of sight from the radar to the target, the so called α, designated as angle 3 (in blue), satisfying

$$\cos\alpha = \sin\phi \cos\theta$$

While the factor is $\cos\theta$, in most cases, not too far away from unity, considering the radar field of view in elevation, the distortion induced by discarding elevation data (and, in fact, using a wrong coordinate system) may still accumulate to a significant divergence of the single-frame estimated ego-velocity and the true ego-velocity. Since tracking ego-velocity involves consistency between frames, this divergence may quickly lead to a complete loss of ego-velocity tracking. This typically happens when a large portion of the detected point-cloud originates from elevated objects, for example driving under a bridge.

CONTINUOUS, INDEPENDENT, AND RELIABLE

The ability to track the car's ego velocity at a basic level is not technically complicated. To do so continuously, independently, and reliably, however, puts high-resolution Imaging Radar miles ahead of the traditional low channel-count radars and alternative sensors on the market to date. The importance of ego-velocity as a feature in the first phase of any advanced driving solution should not be underestimated.