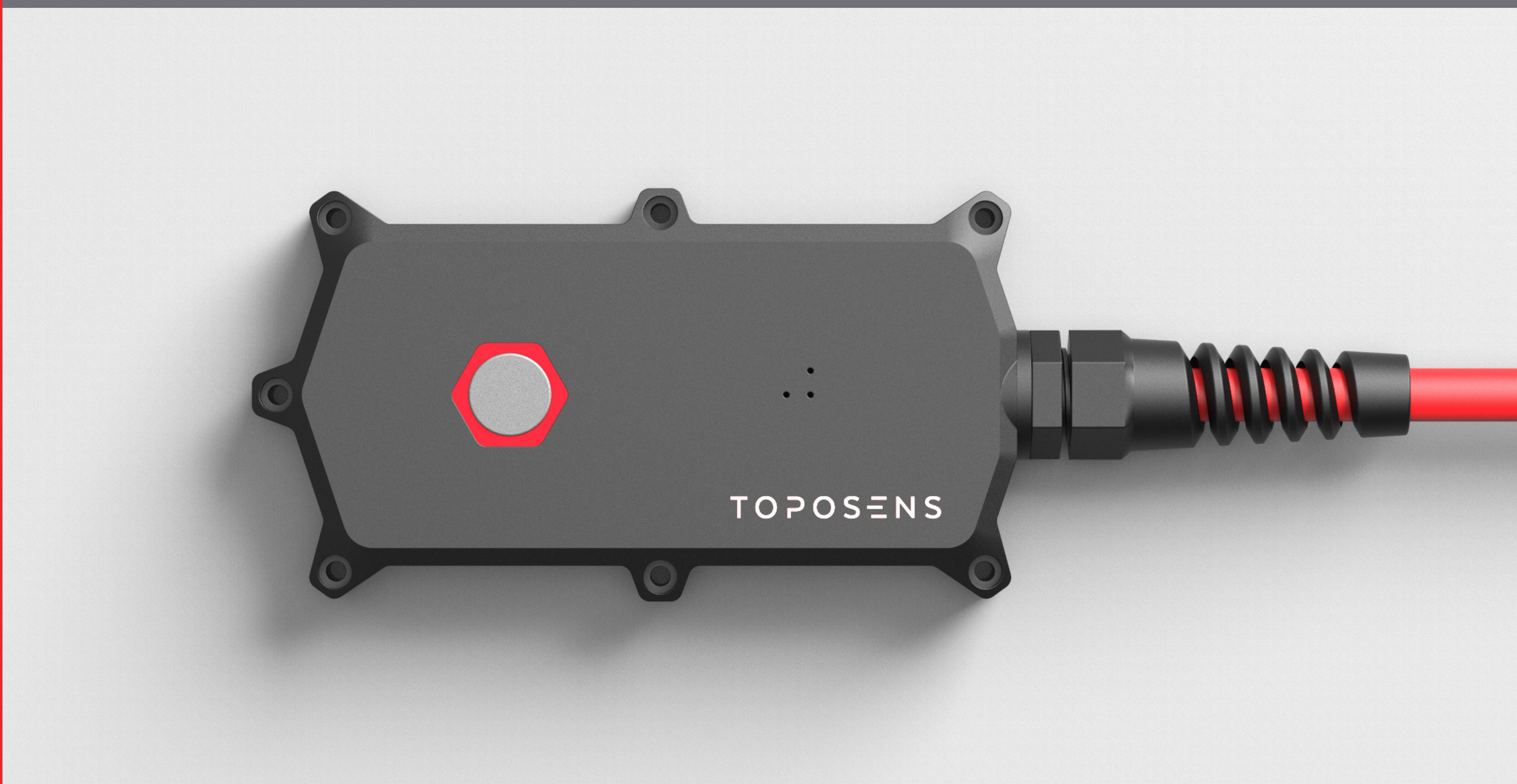
TOPOSENS

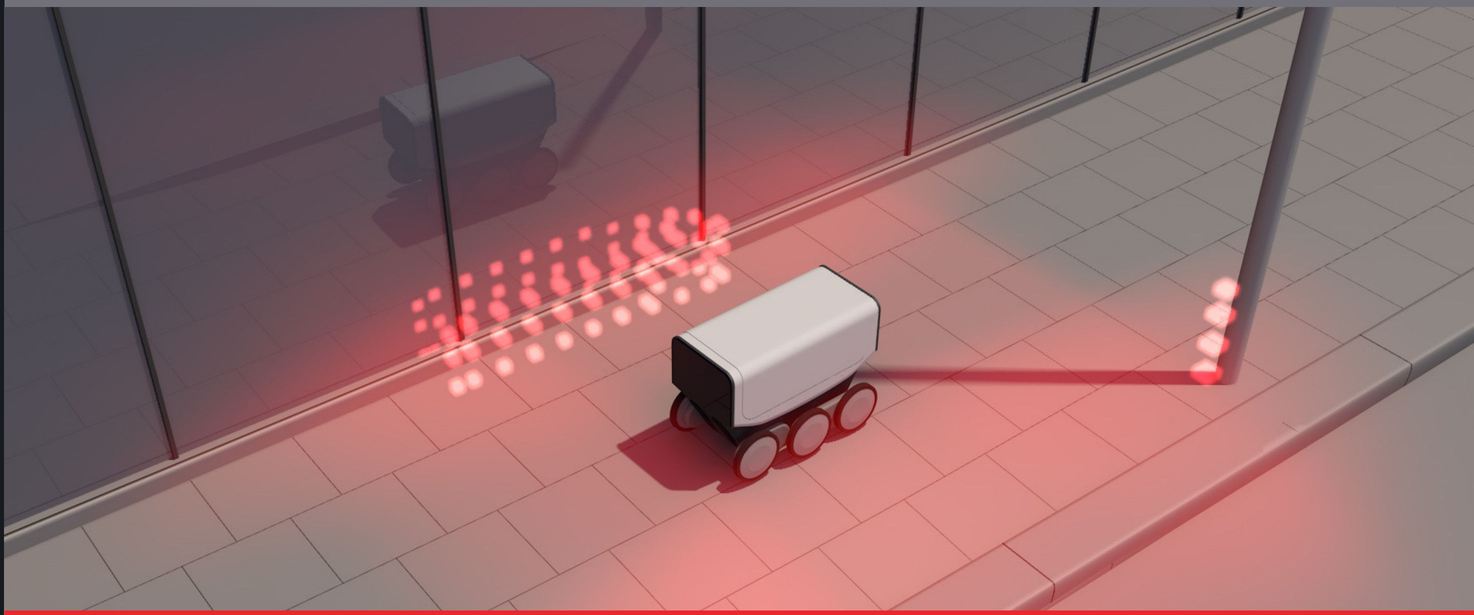
Range-Finding
SENSOR COMPENDIUM



3D Ultrasonic
Echolocation
Sensor Systems

NEXT-LEVEL RANGE FINDING

Content.



Who we are.

Tobias Bahnemann, Alexander Rudoy, Rinaldo Persichini - Founders of Toposens

Toposens was founded in Munich in 2015 and has since grown to consist of over 20 experts in embedded systems, hardware development, 3D sensing, digital signal processing and machine vision.

With our unique 3D ultrasonic technology, we have been gaining experience in a hugely competitive market for several years. It is crucial for us to know the ins and outs of all types of sensors and which applications they are predominantly used for respectively.

This compendium is designed to provide an overview, togehter with a comparison, of the most common sensor systems used in automotive, manufacturing and robotics industries, including their functions, advantages and potential pitfalls.

Sensor jungle navigation.

Status quo

Sensor technologies for environment perception are more of a topic than ever before. Due to ever increasing automation, the demand for range-finding sensors of all kinds is ever growing. They are progressively becoming the human's additional eyes and ears if you like, keeping them safe on the streets whilst also aiding vehicles and autonomous technologies carry out work in a safer and more efficient manner, preventing accidents and damage.

No matter what problems you need to solve with sensor systems, be it drones having to find their setting-off point autonomously or robots needing to navigate their way around a site, sensors are increasingly finding their way into everyday industrial life.

Common environment perception sensors are based on the detection of either radio waves (Radar), acoustic waves (Ultrasound) or light (Cameras and LiDAR). They are further split into passive and active sensors.

Active vs. passive sensors.

Passive sensors (e.g. standard cameras) only receive information from their environment without interacting with it, while active sensors (e.g. Ultrasound, Radar, Lidar) interact with the environment by emitting signals and observing the reflected echos (echolocation).

In general, active sensors output the required range information directly whilst passive sensors need further processing of the captured data to calculate the ranges.

Depending on the type of range finding sensor, the range information can span from simple one-dimensional distance information in one direction to comprehensive three-dimensional distance processing in form of point cloud data, for instance.

Current Detection Devices

Active Safety Devices	Passive Safety Devices
Emit signals and interact with environment	Communication to the environment
SENSOR	**SENSOR**
ToF Camera Structured light camera RADAR Ultrasound LiDAR	Stereo camera Structure from motion
NON-SENSOR	**NON-SENSOR**
Contact bumpers Emergency stop buttons Safety PLCs	Warning lights Audible warning Alarm signals Sign on the vehicles itself

Ultrasonic sensors.

Ultrasonic range finders use a transducer to periodically send out ultrasonic pulses in the air. These pulses get reflected from objects in the sensor's field of view. The echo signals are then detected by the sensor's receiver. By measuring the time it takes for an ultrasonic pulse to travel to the object and get reflected back to the sensor, the distance to the object can be calculated. This principle is called time-of-flight (ToF) measurement.

Typically, high-frequency sound waves are used which are inaudible to the human ear. The frequencies that are used by airborne ultrasonic sensors in the common application areas lie between 40 kHz and 60kHz.

1D Ultrasonic sensors – a reliable solution

These sensors are used to reliably detect objects regardless of their surface quality. Ultrasonic sensors can easily detect glass and mirrored surfaces and are also immune to exposure to light. Therefore, they offer protection in close-range detection and collision avoidance, but are missing a 2D/3D resolution and can therefore not be used for complex navigation and have limitations in 3D collision avoidance of AGVs. The reason why these kind of sensors have been present in the market for some time now are that they are easy to configure, based on low-cost and can detect most obstacles in less challenging scenarios.

- + Cost-efficient sensor solution
- + Low processing power
- + Energy-efficient
- + Robustness

- − Only one-dimensional sensing
- − Low resolution and data quality
- − Low data quality
- − Blind zone in front of the sensor

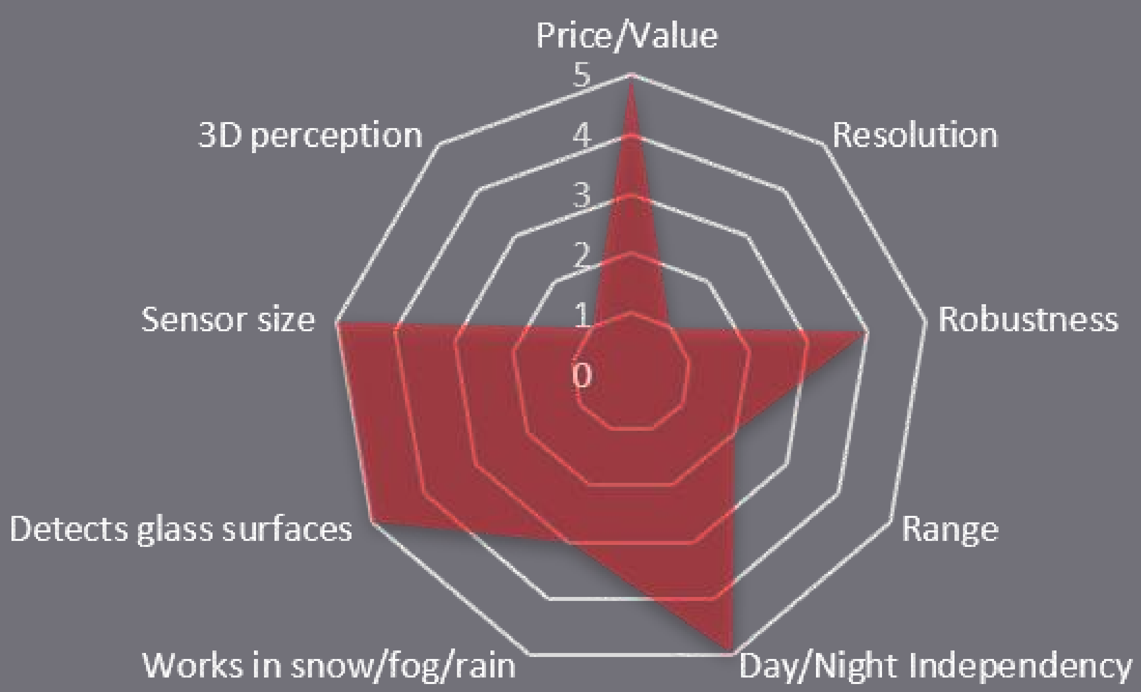
Ultrasonic sensors.

Limitations

Conventional ultrasonic sensors are limited to the detection of objects within one dimension and only calculate distance information via time of arrival echo information These types of sensors can only detect the closest object within a limited opening angle and cannot differentiate between multiple reflections.

Use cases in industries, such as:

- Automotive
- Robotics
- Manufacturing
- Mining
- Military
- Forestry
- Construction



3D Ultrasonic sensors.

3D ultrasonic echolocation sensors are able to calculate the horizontal and vertical position of an object relative to the sensor itself, i.e., they provide 3D coordinates for detected echoes. This localization of echoes in three-dimensional space also allows an advanced ultrasonic sensor to detect multiple objects in a single scan. In that sense, the principle behind the 3D ultrasonics is similar to echolocation, as applied for example by bats.

A typical ultrasonic sensor will normally only output the distance to the nearest object. Because of this, a limited asymmetric opening angle is usually applied for this type of sensor to avoid echo interference from the ground. In contrast, the 3D ultrasonic echolocation sensors allow for symmetric opening angles of up to 180° in ultra short range (10-500mm) and up to 110° at 3m range.

Advanced 3D collision avoidance and object detection

3D ultrasonic sensors perform significantly better than 1D ultrasonic sensors in all performance areas (3D data, opening angle, no blind zone, etc.). They enhance the functionality of 1D ultrasonic sensors, which makes them a great technology for full safety coverage of AGVs in 3D space to reach the highest possible degree of safety. Thanks to their 3D capability and light immunity, 3D ultrasonic echolocation sensors are also able to detect forklift forks and other protruding obstacles.

- \+ Field of view of up to 180° (< 50cm)
- \+ Superior 3D object detection capabilites
- \+ Light immune ultrasonic technology
- \+ Cost-efficient
- \+ Small object detection and no blind zone

- − Limitation in range
- − Alignment
- − Detects shapes only while moving

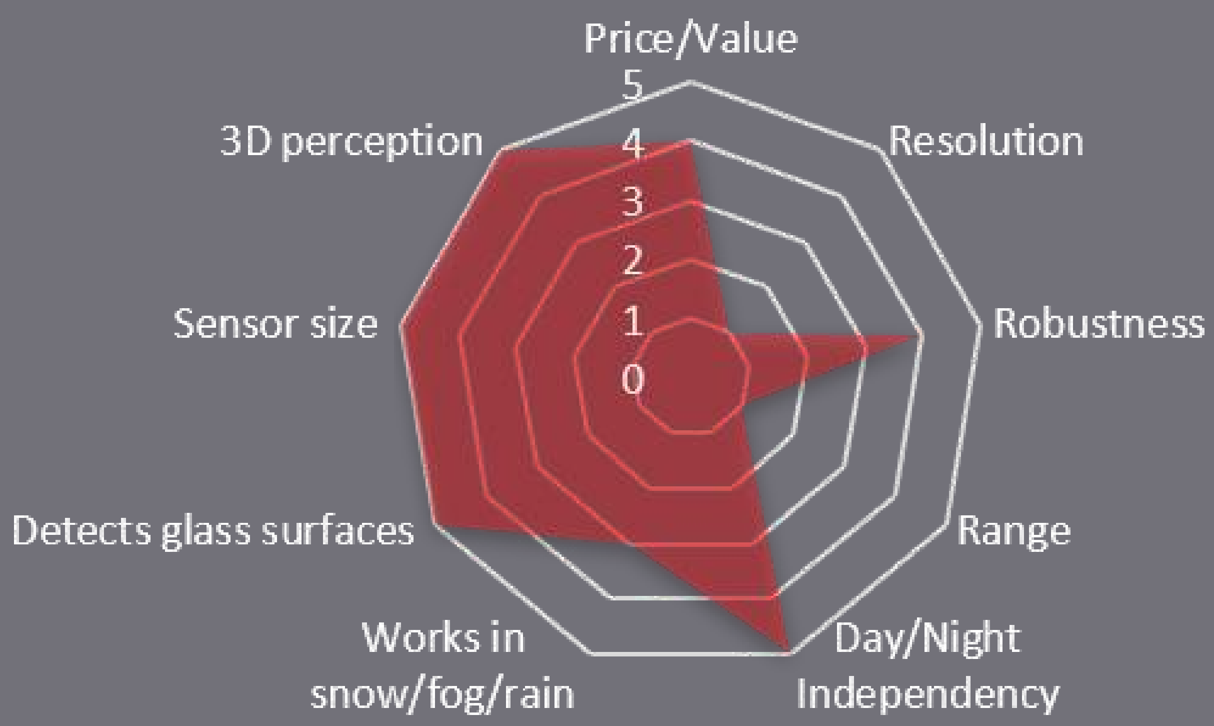
3D Ultrasonic sensors.

Limitations

The limitations are mainly based on the physical properties of ultrasound and the respective reflection characteristics of objects. For the sensor to detect an object, the sent out ultrasonic pulses have to be reflected by the object and received back by the sensor. The reflection characteristics of an object depend on its properties, such as the object's surface size, orientation, and the material characteristics of the object, as well as the relative position of the object to the sensor.

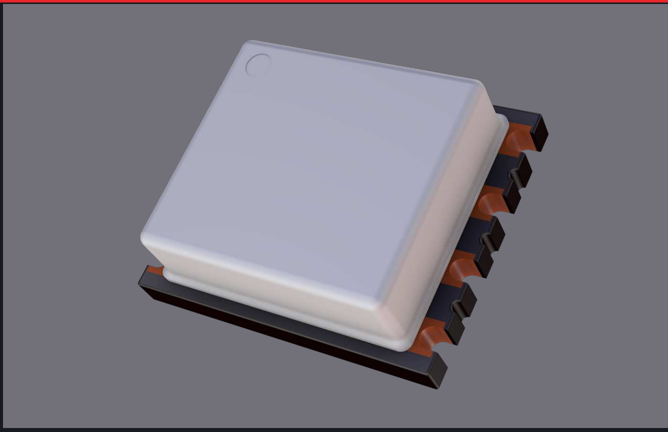
Use cases in industries, such as:

- Automotive
- Robotics
- People Counting
- Building Management
- Gesture Control



RADAR.

RADARs (radio detection and ranging) emit electromagnetic waves and capture the return signal that was reflected by obstacles, similar to the already described ultrasonic sensors. A commonly used type of RADAR is Frequency-Modulated Continuous Wave RADARs (FMCW). By modulating the frequency of the emitted signal, they can determine the distances and the velocities of other objects.



Using the Doppler shift of return to track velocities

Out of all sensors that are listed in this compendium, RADAR is the only technology that can directly output the velocity of obstacles. It does so by making use of the Doppler Shift of return signals from objects that have a different velocity relative to the sensor.

There are 2D RADAR solutions that usually have a low resolution, which requires that multiple radar systems are placed around the AGV. In contrast to 2D RADAR, which provides the azimuth for the direction of an obstacle, 3D RADAR also provides the elevation. These RADAR systems will be utilized for sensor fusion with LiDAR and camera data in the future. Due to dense factory environments, RADARs suffer from reliability challenges due to false positives (falsley detected objects), making them rarely usable in AGV applications.

- + Robust, even under difficult weather conditions
- + Various distances are covered
- + Measurement of velocities using the Doppler Shift technology

- − Moderate data quality & interference in metal environments
- − Blind zone in front of the sensor
- − Small objects, shapes and certain materials are difficult to detect

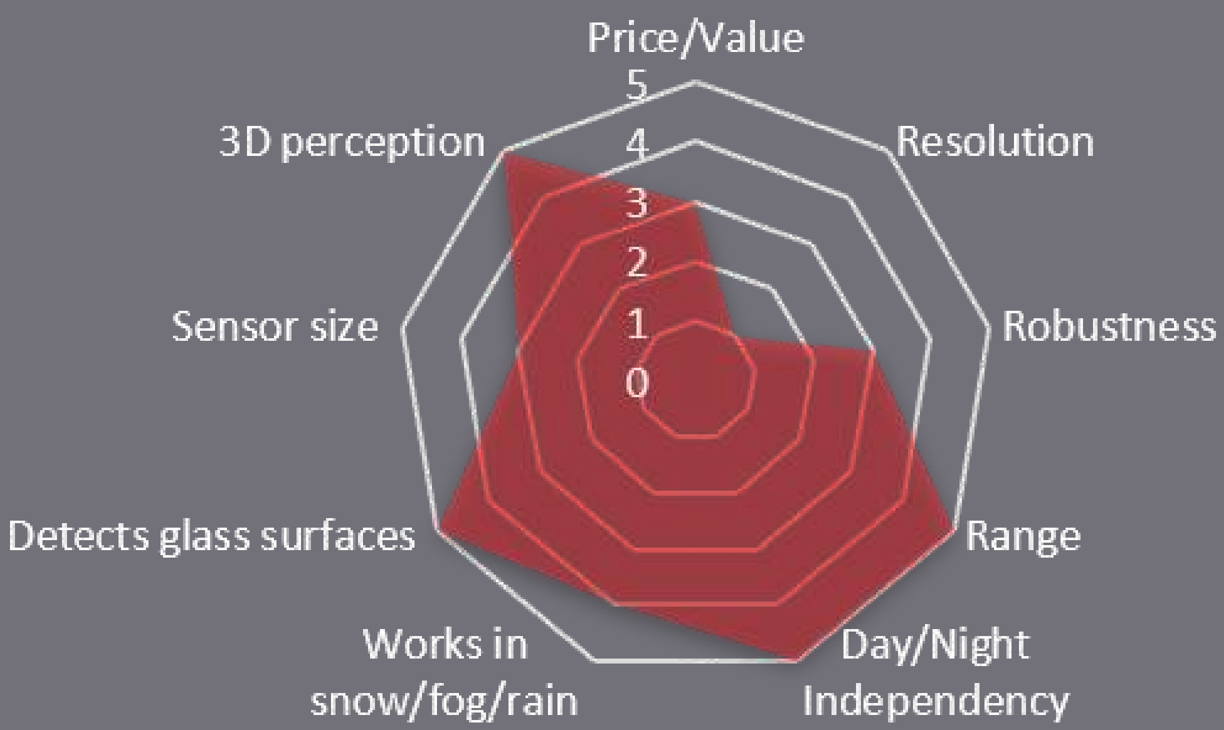
RADAR.

Limitations

Some of the important limitations of radar are related mainly to target resolution, especially when compared to optical sensors (camera). Furthermore, radar tends to struggle detecting those kind of materials which typically absorb radar waves (e.g. uncoated glass, plastics, various wood based materials, drywall).

Use cases in industries, such as:

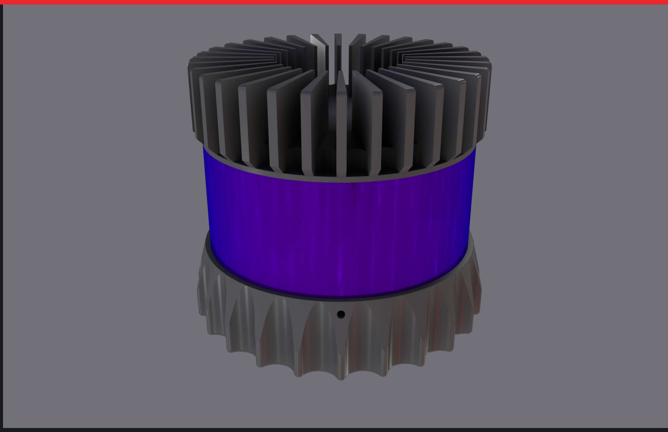
- Automotive
- Robotics
- Agriculture
- Mining
- Military
- Aviation
- Marine



LiDAR - spinning.

LiDAR (Light Detection and Ranging) is making use of echo-reflection using laser beams in the (near-)infrared, ultraviolet or visible spectrum.

By measuring the travel time of these laser beams, LiDAR is able to create a high-resolution 2D or 3D map of the environment. Most LiDAR technologies use pulsed laser beams to illuminate the surrounding environment, some others use continuous-wave signals.



Spinning Lidars (2D or 3D)

2D LiDARs work with a single laser beam. They emit pulses while being in a rotating motion around a horizontal plane and calculate the distance to obstacles. Data is obtained on a horizontal plane. 3D lidars work on the same principle, but with multiple layers of laser beams distributed along the vertical axis, allowing horizontal, rotating scanning. Due to their very high price, 3D LiDARs only have limited acceptance in the market.

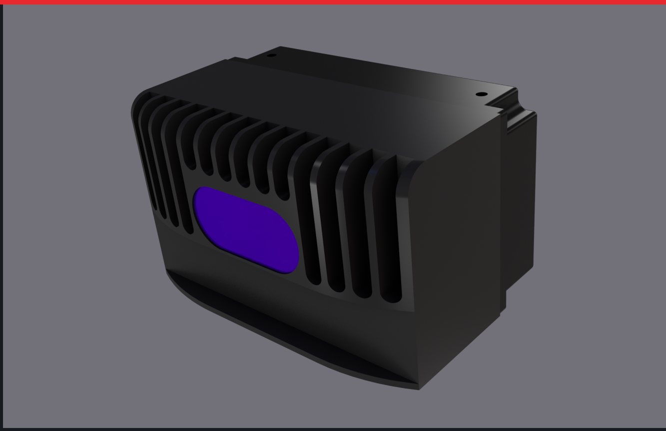
2D LiDARs are one of the most used collision avoidance system in the market, since they are offered with a safety certification for people safety. Due to regulations, this is practivally a must-have security layer for all AGVs. In combination with using the 2D data for navigation, 2D LiDARs are the go-to solution. Big issues though are the high price and their missing 3D-safety capability, due to their limited 2D data resulting in collisions with other objects like forklift forks.

Advantages	Disadvantages
+ Very good resolution	− Limited detection reliability in 3D space
+ High data accuracy	− High price
+ Optimal coverage for long distances and mapping	− Difficulties with certain weather conditions (intense sunlight, rain, fog)
+ Field-of-view up to 270 / 360 degrees	− Limited durability due to moving parts

LiDAR - solid state.

Solid State LiDARs (2D or 3D)

Solid-state LiDARs have no mechanically moving parts. MEMS-based mirrors allow a laser beam to be directed over the surrounding area without motors or gears. The compact chip characteristic of solid-state technology makes these types of LiDARs more robust and also saves space, allowing smaller dimensions to be achieved.



Thanks to the smaller sizes, solid-state LiDARs are a space-saving, robust solution and provide a 3D point cloud with good resolution.
Current generation solid-state LiDAR systems vary on the beam intensity emitted, which directly affects the maximum detection distance. They typically suffer from a trade-off between wide opening angle, resolution and frame rate.

Distinction between 2D and 3D solid state lidars

2D solid-state LiDARs scan on a single plane. These range from short-range (5m) to longer range (100m+). Using time-of-flight laser, they provide high levels of accuracy and are therefore useful for both indoor and outdoor obstacle detection. Still quite new to the market, 3D solid-state LiDARs, however, add another dimension to 2D LiDAR sensors, providing the AGV with 3D point cloud data.

- + Good resolution
- + High data accuracy
- + Optimal coverage for long distances and mapping

- − Small field of view
- − High price
- − Difficulties with certain weather conditions (intense sunlight, rain, fog)
- − Processing big datasets causes high power consumption and compute need

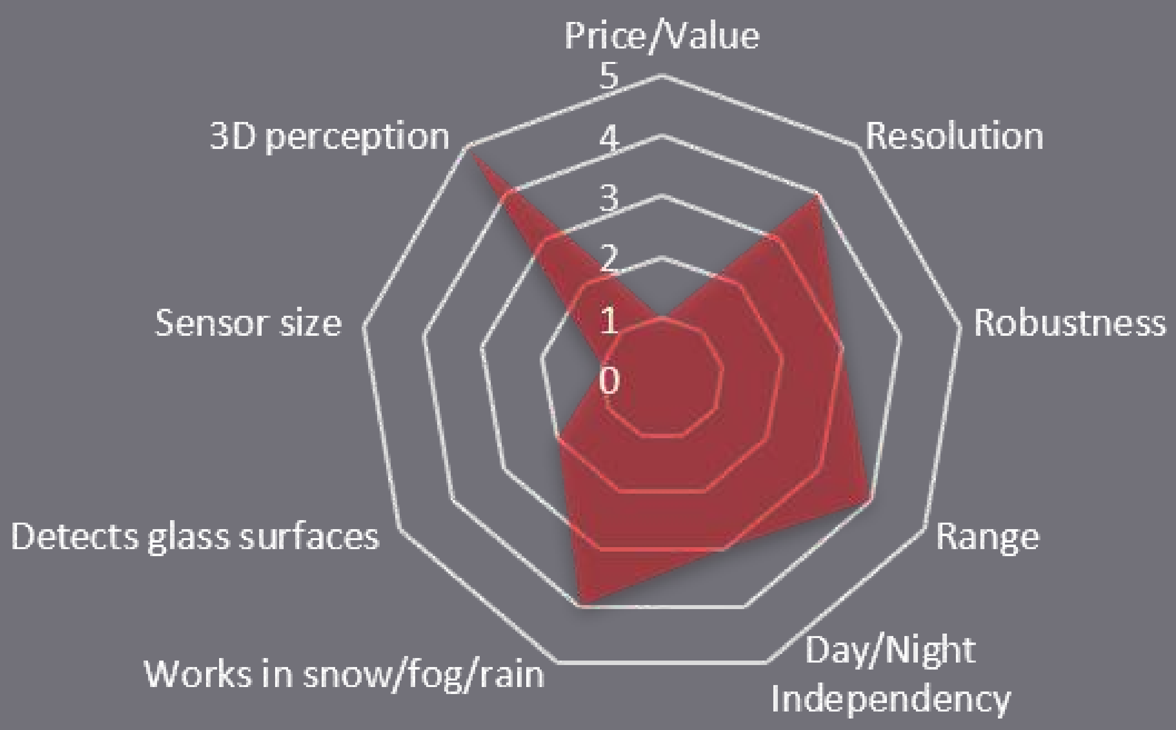
LiDAR - spinning & solid.

Limitations

The data quality of LiDAR is extraordinary. However, whilst prices for LiDAR systems have dropped significantly due to reduced amounts of moving parts, they are still the most expensive solution for depth sensing, costing 100 - 1000 times more than ultrasonic sensors. Especially spinning LiDARs, which are larger than other sensors. Future LiDAR systems will be solid state with enhanced output power and beam geometries. 4D capabilities have been demonstrated for LiDAR technology which includes target velocity in the outputted data.

Use cases in industries, such as:

- Automotive
- Robotics
- Manufacturing
- Mining
- Military
- Forestry
- Construction



Camera sensors - passive.

Whilst LiDAR (as well as RADAR and ultrasonic sensors) measure the ToF differences from actively emitted signals, cameras usually only passively receive light from the surrounding environment. They detect light within the visible or infrared spectrum. Different types of cameras use different approaches to extract range information from this data.

Mono and wide-angle cameras

These camera sensors typically provide an image of the surrounding environment. When implemented with a moving object, a mono camera can also create a 3D image of multiple photos from different angles ("Structure From Motion"-principle).

Stereo cameras

Stereo camera sensors capture the same scene with two cameras, measuring distances and generating 3D data through triangulation, which probably makes them the most precise sensors when it comes to measuring 3D geometries. Newer cameras offer on-chip processing and are capable of edge-detection. Their output is an image that consists of edges instead of color information. This simplifies the 3D image reproduction for stereo cameras or structure by motion algorithms.

Out of all described sensors, cameras are the best for semantic segmentation and classification of obstacles but suffer from reliability issues due to their depedency on light and light reflectivity of objects.

Advantages	Disadvantages
+ Detailed information about environment	− Limitated reliability in detecting transparent, black or shiny objects
+ Many different applications	− High price
+ No problem with sound-absorbing or tilted objects	− Weather-dependent functionality
+ Object classification capabilities	− Processing big datasets causes high power consumption and compute need

Camera sensors - active.

Structured Light Cameras

They actively emit signals in the surrounding environment to measure the return signals. One of those camera techniques are Structured Light Cameras that project a light pattern into the environment.

From the distortion of this pattern onto an arbitrarily shaped surface, the 3D geometry of this surface is produced.

ToF Cameras

They can capture an entire scene by emitting a light pulse and measuring the time-of-flight of the return signals for each pixel being processed into 3D data.

Thermal cameras

Cameras are not only limited to visible light. Thermal cameras use infrared light to produce a thermal image. They are a reliable sensor technology for pedestrian detection, work similarly well during day and night, and offer a good resolution of the surrounding environment. Due to their limited object detection capabilities, they are currently not widely used in the AGV market.

+	−
Detailed information about environment	Lots of data processing needed
Many different applications	High price
No problem with sound-absorbing or tilted objects	Weather-dependent functionality
Object classification capabilities	High power consumption

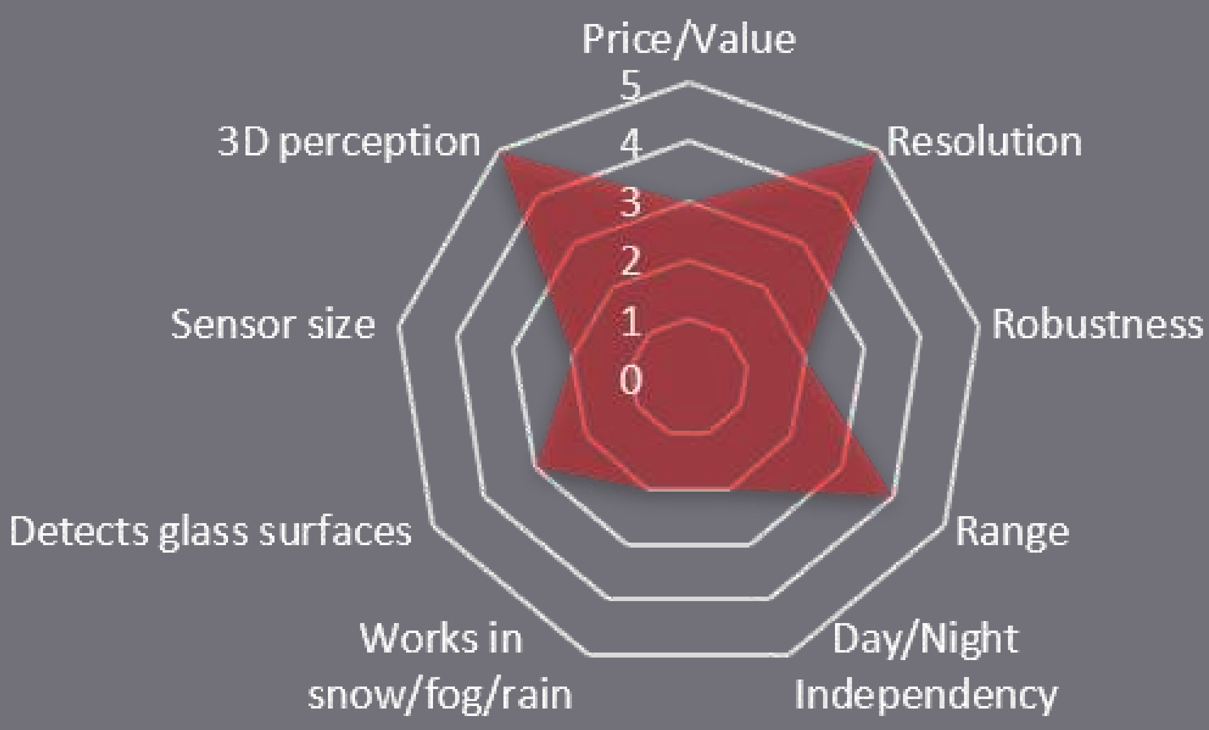
Camera - passive & active.

Limitations

Camera data quality depends a lot on the environmental conditions (e.g. weather) which reduces their reliability. Rain, as well as fog or direct sunlight, can seriously reduce the data quality. For stereo cameras, the opening angle is often limited and the technology itself is quite expensive. For thermal cameras, precise distance measurements are difficult and ranges can only be roughly determined

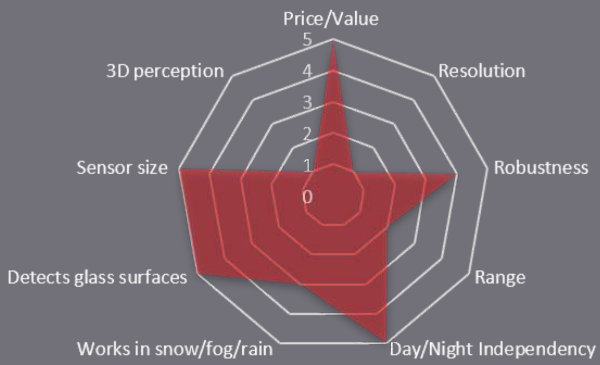
Use cases in industries, such as:

- Automotive
- Robotics
- Agriculture
- Mining
- Military
- Aviation
- Marine

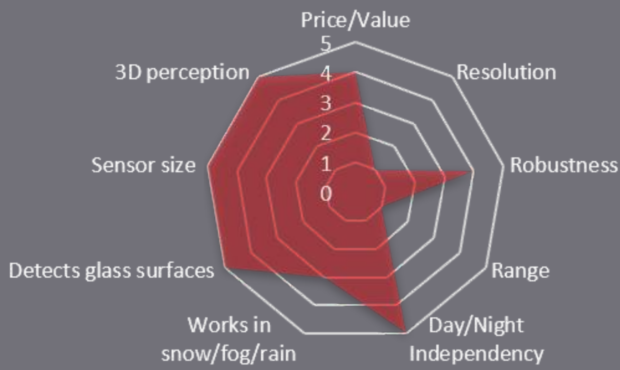


Feature comparison.

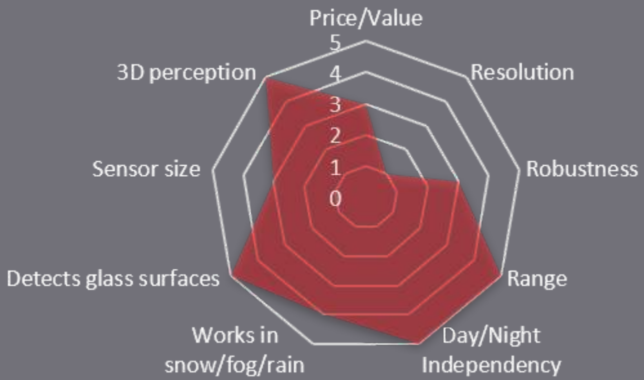
Ultrasonic Sensor



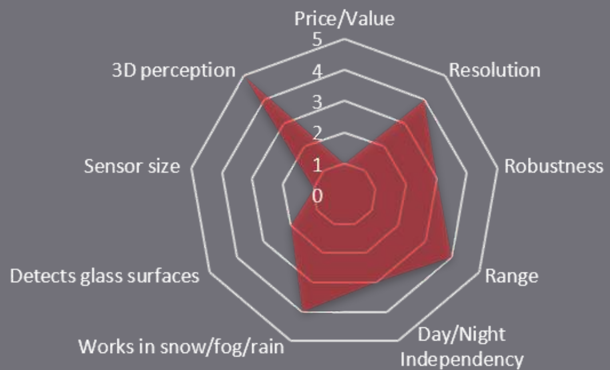
3D Ultrasonic Sensor



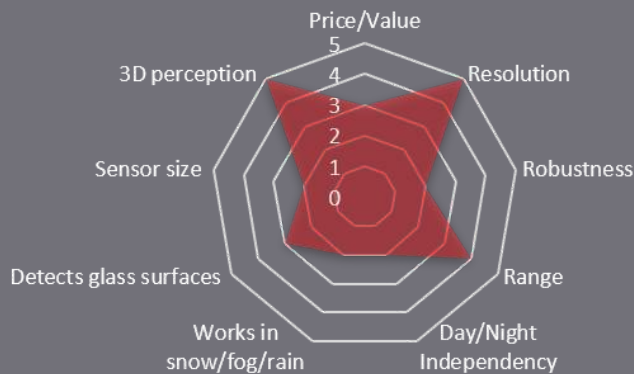
Radar



Lidar



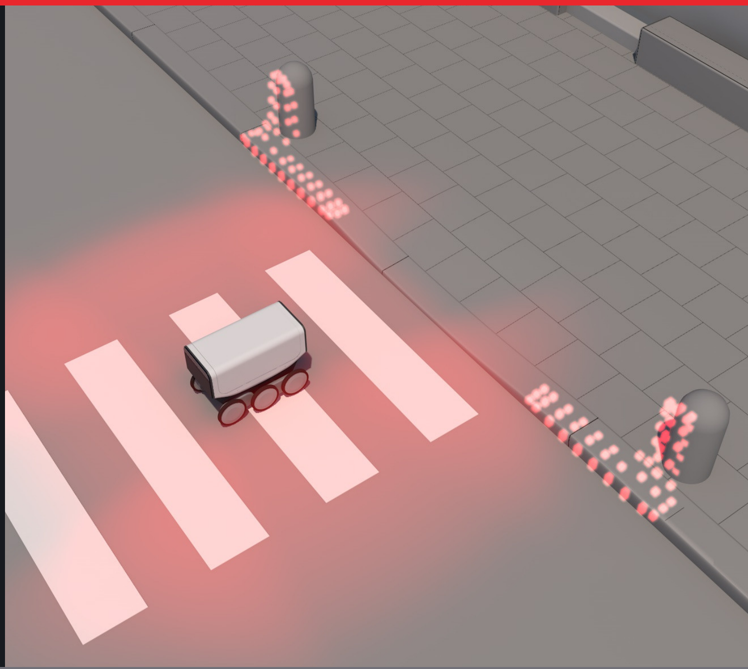
Camera



USPs of Toposens sensors.

"Toposens provides the world’s first 3D ultrasonic sensor solution for best-in-class three-dimensional positioning."

Tobias Bahnemann
CEO & Founder, Toposens GmbH



Locate multiple object positions in 3D, based on proven ultrasonic technology.

Easily integrable via CAN interface and low calibration effort.

Use our robust, energy efficient sensors in a wide variety of industries.

Detect objects in the dark, through dust, dirt and in other lighting conditions.

Summary.

This compendium serves to summarize the most commonly used range-finding sensors, which by and large reflect only a fraction of all sensor types available on the market. There are countless other types of safety systems available, such as optical infrared sensors, light barriers and machanical sensors such as bumpers, to name but a few.

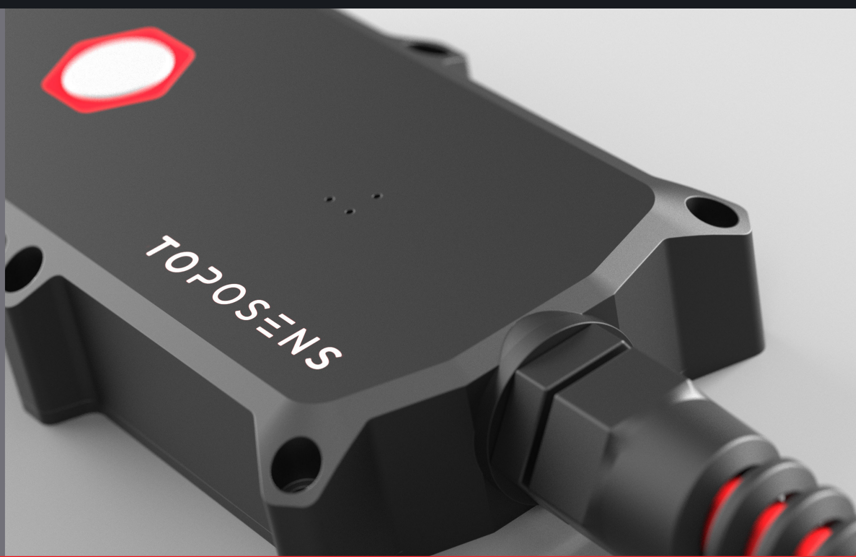
We are linving in fast-moving times of exponential technologies, where autonomous and automated processes are constantly evolving and increasingly taking over traditional manufacturing practises. Hence, a considerable amount of expectations and responsibilities are placed upon sensor technologies, especially in the robotics and automotive sectors.

While we are on the verge of developing autonomous driving, even more robots will find their way into our everyday lives. Every type of sensor described in this compendium will play an essential role in future developments of technologies.

LiDAR and sonar technology, for instance, will become increasingly important for automotive and robotics applications. Our ultrasound-based 3D technology opens many new application areas. As far as autonomous driving is concerned, we believe that all the sensors presented in this compendium will play a key role of their own:

Ultrasound - will play a decisive role in short-range detection.
RADAR - mainly for speed measurement and distance detection.
LiDAR and Cameras - for a very precise, real time vizualisation of the environment.

Regardless of which type of sensor will ultimately play a major role, we live in the most exciting and rapidly evolving times in which we have the chance and responsibilities to lay the foundations for future technologies.



Contact Us.

CONTACT US NOW TO START YOUR PROJECT

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This report is part of a project that has received funding by the European Union's Horizon 2020 research and innovation programme under grant agreement number 953716.

Vision FOR TECHNOLOGY