

SICK AG WHITEPAPER

HDDM⁺ – INNOVATIVE TECHNOLOGY FOR DISTANCE MEASUREMENT FROM SICK

2017-11

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SUMMARY

This white paper describes the many advantages of HDDM⁺ optical distance measurement technology in different applications. HDDM⁺ (High Definition Distance Measurement Plus) is a high-resolution time-of-flight process for non-contact distance measurement that is used in distance sensors as well as in 2D or 3D LiDAR sensors.

The technology is suitable for indoor and outdoor use, for measuring the distance to diffusely reflecting objects and to retro-reflective reflectors. The sensing range of distance sensors with HDDM⁺ is up to 1.5 km on retro-reflective tape. In contrast to single pulse or phase correlation technologies, HDDM⁺ is a statistical measurement process. This means that the sensor statistically evaluates the echoes of multiple laser pulses to calculate a distance value. Furthermore, thanks to HDDM⁺, sensors can also be equipped with multi-echo capability. If there are several echoes, the sensor identifies and selects the relevant echo for evaluation. This enables distance measurements with high measurement certainty, even under difficult ambient conditions.

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Technological principles

Optical distance and LiDAR sensors

Optical distance sensors as well as 2D and 3D LiDAR sensors (LiDAR = light detection and ranging) are used in a wide range of industries and applications. The spectrum of applications ranges from distance measurement in the micrometer range, e.g., quality control for the electronics production industry, to multi-dimensional object detection and position determination with 2D and 3D LiDAR sensors in mechanical and plant engineering, and even to determining the position of industrial cranes or vehicles on rails. Depending on the distance range, requirements for measurement accuracy and repeatability, and ambient conditions, different measurement principles are used that are ideally suited to the respective application situation.

Time-of-flight measurement

Time-of-flight measurement is an indirect process used to determine the distance to a target object. For this purpose, the sensor emits a light beam in the direction of the target object. This light beam is usually laser light with wavelengths in the visible or near-infrared range. The sensor receives the light that is reflected by the target object. Using the speed of light, the distance between the sensor and the target object is calculated based on the time of flight of the light.

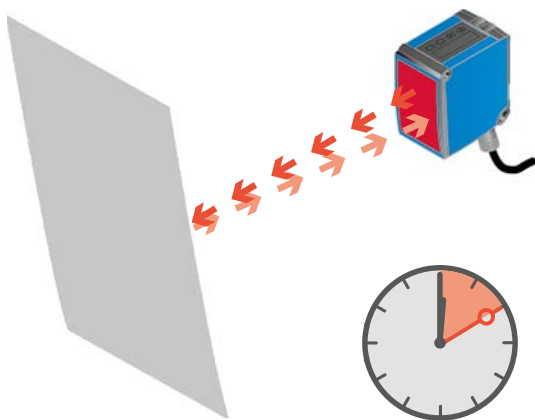


Fig. 1: Basic presentation of the time-of-flight measurement.

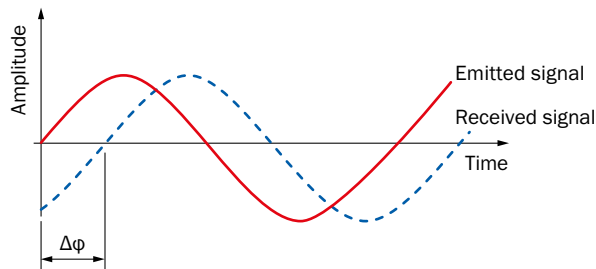
The distance measurement is practically independent of the target object's surface properties. Time-of-flight measurement is therefore suitable for one-dimensional distance measurement as well as for multi-dimensional measurement with LiDAR sensors that detect areas or solid angles.

Almost all LiDAR sensors that are currently used worldwide in industrial applications operate according to the following principle: The sensor's laser beam detects the objects that are present in its scanning area; the sensor's receiver unit then measures the reflected light. An image of the detection range is created by taking into account the angle at which the sensor emits and receives the laser beam and the time of flight.

The 850 nm and 905 nm infrared-light wavelengths, which are frequently used in time-of-flight measurements, are invisible to the human eye. This is a significant advantage in many applications. For example, infrared-based 2D LiDAR sensors are used to secure artwork in museums. Furthermore, the invisible laser light does not disturb employees in working environments. A visible alignment laser is used in most cases in order to align an infrared distance sensor with the measuring object. External infrared viewing devices are often used to visualize the scanning areas of infrared-based LiDAR sensors. The measuring laser can be directly used to mechanically align the sensor for distance measurements with visible light.

Phase correlation measurement process

In the phase correlation measurement process, the sensor emits a continuous amplitude-modulated light beam. The distance between the sensor and the target object is determined from the phase shift of the modulation between the emitted and the received light.



$$s = \frac{a \cdot \lambda + R \cdot \lambda}{2}$$

a = Number of wavelength cycles

λ = Wavelength: $\lambda = c_0 / f$

(c_0 = Speed of light in the vacuum, f = frequency)

R = Fraction of a single wavelength: $R = \Delta\phi / 2\pi$

($\Delta\phi$ = Phase shift)

s = Distance measurement

Fig. 2: Principle of operation of the phase correlation measurement process.

The phase correlation measurement process is particularly suitable for fast, high-precision distance measurement for objects that move continuously along the laser axis. This type of axial object tracking is used, for example, for determining the position of storage and retrieval systems in fully automated high-bay warehouses. The distance sensor usually moves with the storage and retrieval system and measures the distance to a fixed reflector at the end of the aisle.

Optical pulse time-of-flight measurement

With pulse time-of-flight measurement, the sensor emits short light pulses which are partially reflected by the target object. The sensor determines the temporal difference between sending and receiving the pulse, and uses this information to calculate the distance between itself and the object. Pulse time-of-flight measurement distinguishes between deterministic and statistical processes. With deterministic pulse time-of-flight systems (single pulse), the sensor emits individual laser pulses and determines a distance value from the time of flight of each pulse. In contrast, statistical pulse time-of-flight systems emit a series of pulses over a very short period of time. Using statistical methods, a distance value is calculated from the received echoes of a series. Therefore, even if one or more echoes of a series are lost due to faults in the measurement path, a valid distance value can still be determined with high measurement certainty.

In contrast to the phase correlation measurement process which uses a continuous light beam, the individual pulses of the pulse time-of-flight systems feature a higher peak power by several orders of magnitude. As a result of their operating principle, pulse time-of-flight systems can be designed to be more resistant to ambient light – a typical factor in outdoor applications.

HDDM+ measurement process

HDDM+ (High Definition Distance Measurement Plus) is a high-resolution time-of-flight process for non-contact distance measurement that is used in distance sensors as well as in 2D or 3D LiDAR sensors. Developed from the proven HDDM technology, HDDM+ is suitable for indoor and outdoor use, as well as for measuring the distance to diffusely reflecting objects and to retro-reflective reflectors. The sensing range of distance sensors with HDDM+ is up to 1.5 km on retro-reflective tape. In contrast to single pulse or phase correlation technologies, HDDM+ is a statistical measurement process. This means that the sensor statistically evaluates the echoes of multiple laser pulses to calculate a distance value.

Furthermore, thanks to HDDM+, sensors can also be equipped with multi-echo capability. In some applications, the sensor receives multiple echoes due to multiple reflections of the light beam. Such (false) echoes can be caused by, for example, measuring through protective screens, rain, snow, fog, or dust.

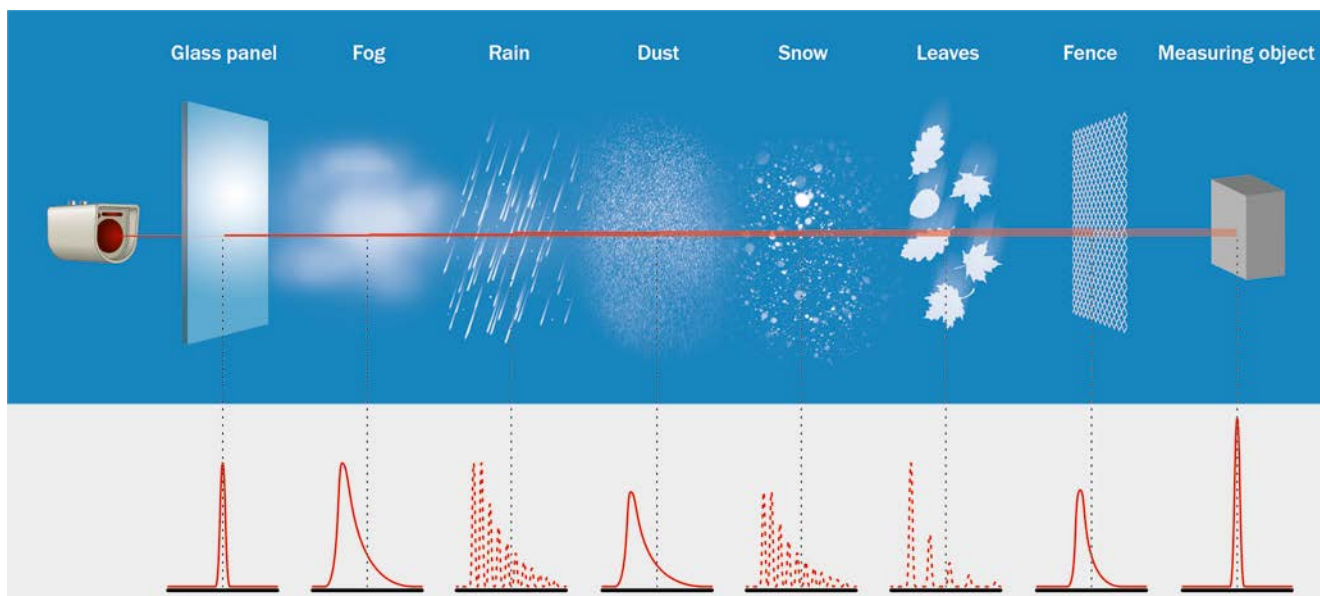


Fig. 3: The diagram illustrates the multi-echo capability of the Dx1000 distance sensors from SICK. They can distinguish up to 8 echoes per measurement due to reflections along the measurement path.

As a rule, only one of the received echoes represents the real distance between the sensor and the target object. The other echoes can lead to inaccurate measurements. The multi-echo capability of the HDDM+ technology enables the Dx1000 distance sensor and MRS1000 3D LiDAR sensor to identify the relevant echo among multiple echoes, to evaluate only this echo, and to transmit it to the connected control. The unwanted echoes can be blanked.

In the example of the Dx1000 distance sensor, the SOPAS ET user interface enables you to represent the detected echoes as a function of the object distance in a diagram on your PC, and to select the relevant echo. To do this, you can define a region of interest (ROI). Echoes within the ROI are evaluated, whereas echoes that fall outside the ROI are discarded. You can therefore perform distance measurements on remote measuring objects through a wire fence by setting the ROI in such a way that the relevant echo of the measuring object falls within the ROI, and the fence echo falls outside the ROI. In addition, you can select the first or last of the existing echoes within the selected ROI for evaluation.



Fig. 4: Diagram defining the region of interest of the Dx1000 distance sensor from SICK.

This enables you to perform distance measurements even on mirroring surfaces. An example is the level measurement of liquid aluminum. In the absence of an oxide film on the liquid aluminum, the distance sensor laser is reflected in a targeted way by the mirror-like surface. If the light beam is directly reflected into the receiver optics of conventional laser distance sensors, this usually leads to inaccurate measurements and faults. To prevent this, the distance sensor is usually aligned a few degrees away from the surface normal. The sensor still receives an echo from the measuring object. However, because a significant portion of the light beam is reflected by the reflective surface past the sensor receiver optics into the background, the sensor generally receives a second echo from a background reflection, e.g., on a ceiling. In the case of conventional distance sensors with time-of-flight technology, the simultaneous detection of two echoes usually leads to inaccurate measurements or even faults. With HDDM+ multi-echo technology, on the other hand, the false echo can be identified and blanked by setting the ROI accordingly. This enables you to measure the distance to the reflective surface with high measurement certainty.

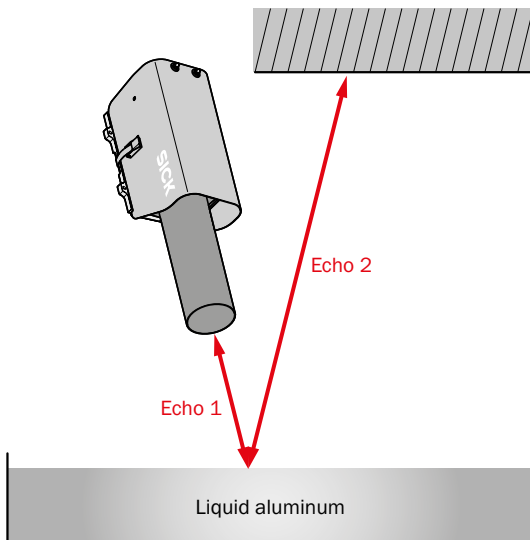


Fig. 5: Multiple-echo situation with distance measurement on a liquid aluminum surface.

The multi-echo capability of the HDDM+ technology enables the LMS1000, MRS1000, and TiM100 LiDAR sensors to represent object edges in an extremely precise manner. If the measuring laser touches the object edge with its finitely large light spot, an object behind it usually generates a second echo. The multi-echo capability of HDDM+ reliably prevents the two echoes from being mixed up and provides an accurate image of the object edge.

Distance and LiDAR sensors equipped with HDDM+ are particularly suitable for outdoor use. This is because they have a high degree of resistance to ambient light, precipitation, fog, or dust in the measurement path. This resistance to ambient light results from the statistical evaluation of the echoes. False echoes due to a high photodiode current induced by ambient light, which can lead to inaccurate measurements in single-pulse measurement processes, are effectively filtered out. For trouble-free measurements in rain or snow, the multi-echo capability also enables you to effectively filter out short-term reflections of the measuring laser. In addition, the HDDM+ technology can suppress unwanted reflections caused by fog or dust in the measuring range.

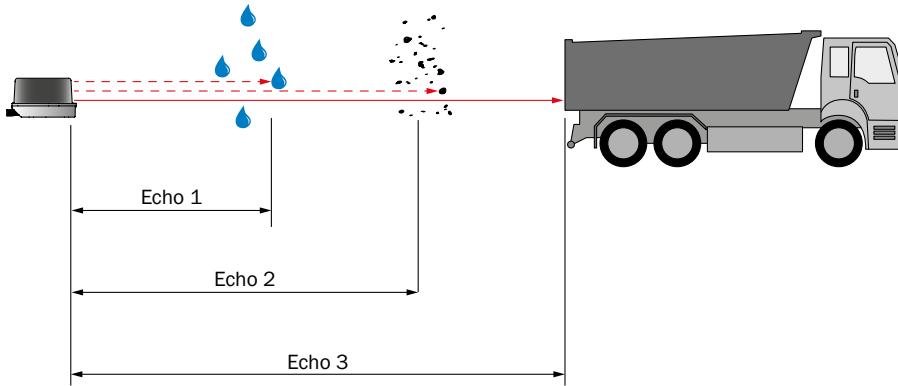


Fig. 6: Basic presentation of the multi-echo capability of the LMS1000 and MRS1000 LiDAR sensors from SICK in the event of dust, rain, snow, or fog on the measuring path.

Collisions between rubber tired gantry cranes in ports, for example, can be prevented by permanently monitoring the movement range with an MRS1000 3D LiDAR sensor. The multi-echo technology enables a reliable distinction to be drawn between false echoes due to rain or fog and the echoes of containers and other obstacles in the movement range. In this way, collisions can be reliably avoided and high availability is achieved at the same time.

HDDM+ also makes it possible to adapt the sensing range of a distance sensor to the individual application by selecting the appropriate measurement cycle time. The state of the art method is a minimum measurement cycle time of 1 ms for highly dynamic applications. If the main priority for the measurement is a large sensing range and the best possible repeatability, this can be achieved by extending the measurement cycle time. Depending on the remission of the target object, sensing ranges of several hundred meters can therefore be achieved when measuring the distance to natural target objects. Reflectors such as Diamond Grade reflective tape are detected reliably by the DL1000 distance sensor even at a distance of one and a half kilometers. The same sensor can also perform distance measurements up to a minimum distance of 20 cm. Thanks to the HDDM+ technology, it is possible to reliably determine a low-noise distance signal despite extremely different signal levels.

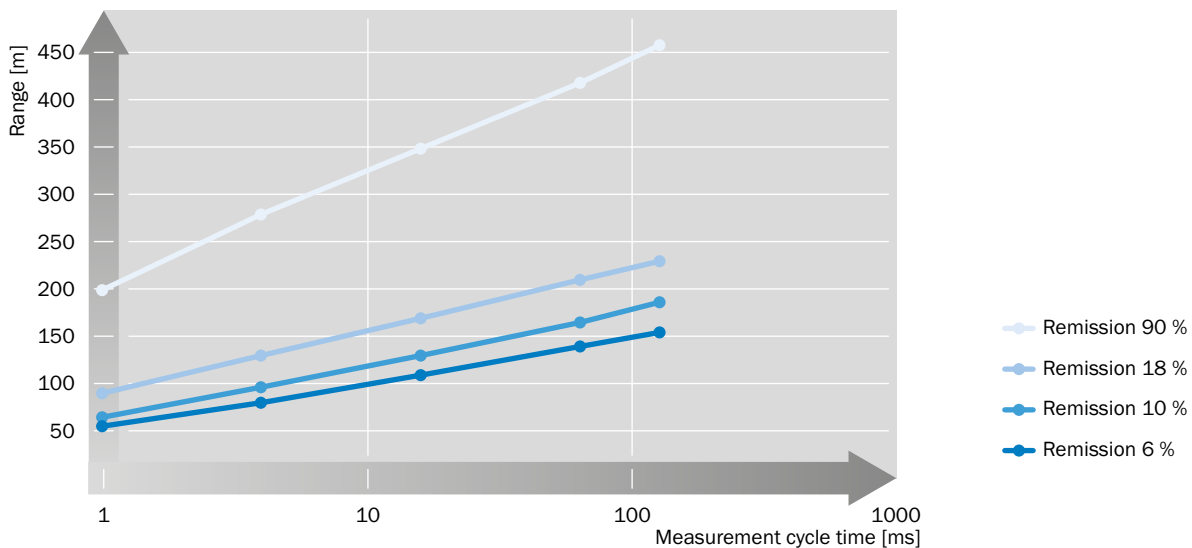


Fig. 7: By setting the measurement cycle time, the sensing range of the DT1000 distance sensor from SICK can be adapted to the respective application for measurements on natural target objects (i.e., not retro-reflective objects). The remission is an (object-dependent) measurement for the reflection of the measuring laser on the measuring object.

HDDM⁺ is particularly suitable for measurements on hot surfaces, for example when measuring the level of liquid steel or determining the position of steel slabs during the continuous casting process. Depending on their emissivity, objects with temperatures above approx. 700 °C emit a significant proportion of their heat radiation in the near-infrared range. This can lead to inaccurate measurements or even sensor failure in conventional infrared light-based time-of-flight processes.

While the phase correlation measurement process is primarily suitable for axial object tracking, both continuously changing distances and sudden changes in distance can be detected with HDDM⁺. Sudden distance changes occur, for example, if objects move into a distance sensor's measuring laser from the side, or during object detection with a LiDAR sensor, where the measuring laser passes over the objects present in the detection range. In the case of LiDAR sensors based on deterministic pulse time-of-flight processes, a distance value is assigned to each individual laser pulse. By contrast, the large number of laser pulses per angular segment in the case of LiDAR sensors with HDDM⁺ technology cause the laser light spots to overlap. This means that the entire scanning area is fully detected without any gaps.

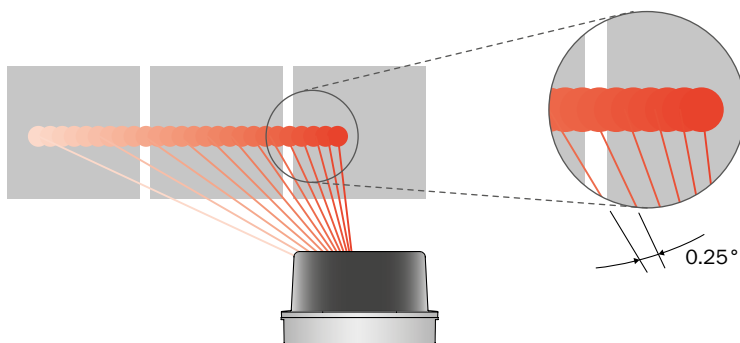


Fig. 8: Gap-free detection of the scanning area with the MRS1000 LiDAR sensor from SICK.

REFERENCES

→ www.sick.com/micron-to-mile