"OUR" SENSORS

In our series of lecture sections about sensors, we will describe certain popular powerful sensors.

- RGB camera
- LiDAR (aka Laser scanner)
- Depth Camera (and dual RGB-Depth)
- IMU (Inertial Measurement Unit)
- GPS

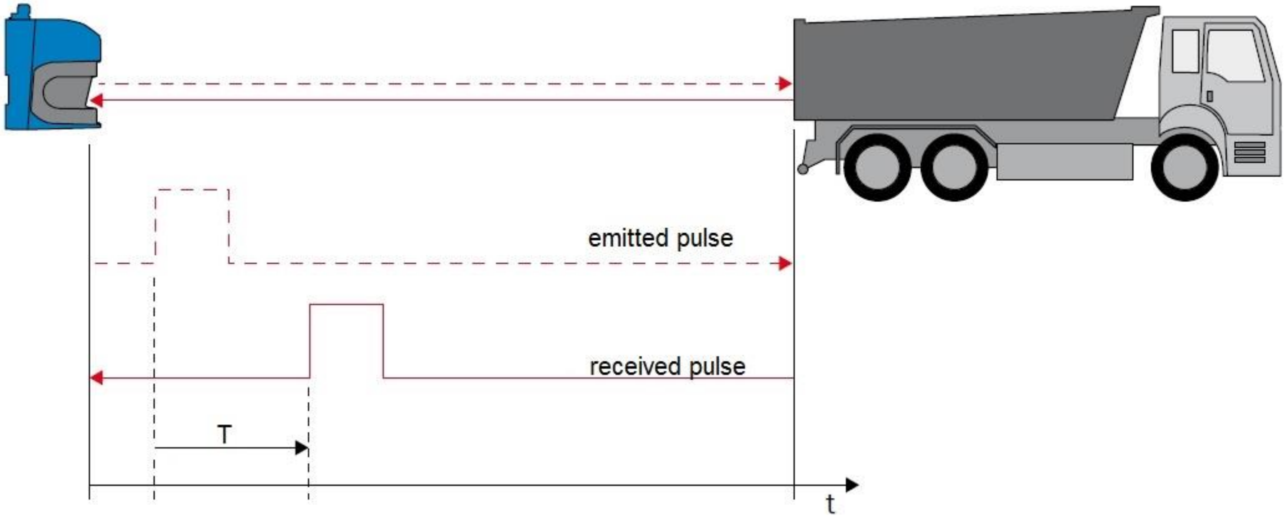
In addition to the description of those sensors we will see, in real-time, some industrial models working (Depth cameras, 2D LiDARs and IMUs.)

Light Detection and Ranging (LiDAR)

WORKING MECHANISM

- A pulsed laser beam can be used to measure distance.

The pulse of coherent light is emitted in a particular direction and the reflected signal is measured, to evaluate the delay of the reflected pulse.



The delay T is known as "Time of Flight" (ToF)

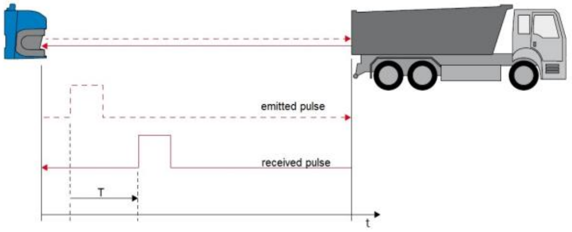
which would be T=**c***D; being D the travelled distance, and **c** the speed of the light.

The travelled distance D, is twice the distance to the reflecting surface.

(image from https://www.sick.com/au/en/detection-and-ranging-solutions/2d-lidar-sen)

We find some technical issue here (as it usually happens)

The ToF must be measured: hardware is not perfect, it introduces errors in the measurement of the ToF.



To put this in context: **c**~300,000km/s = 3E8m/sec

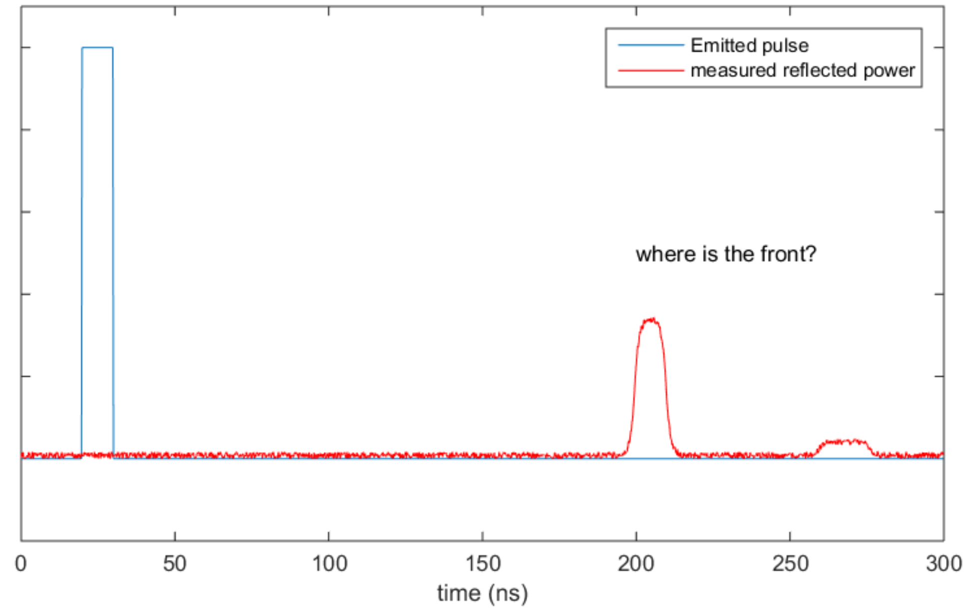
L=1m → T = (1m)/**c**~ 3.3ns.

L=100m → T = (100m)/**c**~ 333 ns.

If we want an accuracy of 1 cm: dL=1cm →dT ~ 0.034ns (<4% of a ns!)

(you would not do that using an Arduino loop!)

The reflected signal is polluted by noise, and by other echoes, and is also distorted, and that distortion depends on the relative inclination/shape of the spot of surface being illuminated by the laser beam.



And from that, the HW measure/estimates the ToF, with an accuracy of 0.04ns, for achieving an accuracy of 1cm.

And yet, a common commercial LiDAR can achieve 1cm accuracy, and ranges of 100m.

(I have exaggerated the spread of the distorted reflected pulse, in the plot. I think its flanks should evolve in intervals of about 3ns, based on some estimations I tried.)

(but that is not our business , in MTRN4010)

- A pulsed laser beam can be used to measure distance.

The pulse of coherent light is emitted in a particular direction and the reflected signal is measured, to evaluate the delay of the reflected pulse.

- The propagation time is used to estimate distance (as the speed of EM waves is a well-known constant).
- This process can be repeated tens to hundred of thousands of times /second (in theory even millions!).
- If the same process is repeated at different directions, a surface can be scanned.
- Typical laser scanners operate in a plane of scanning (2D).
- More advanced ones do scan in 3D (2D angles, elevation and azimuth)

- This process can be repeated tens to hundred of thousands of times /second (in theory even millions!).

Millions? Why? (where is that limit from?)

For measuring distances in the range 0m<d<100m, the reflection would take, in the worst case (L=100m), a ToF T=100m / c ~333.4ns~0.33 microsecond.

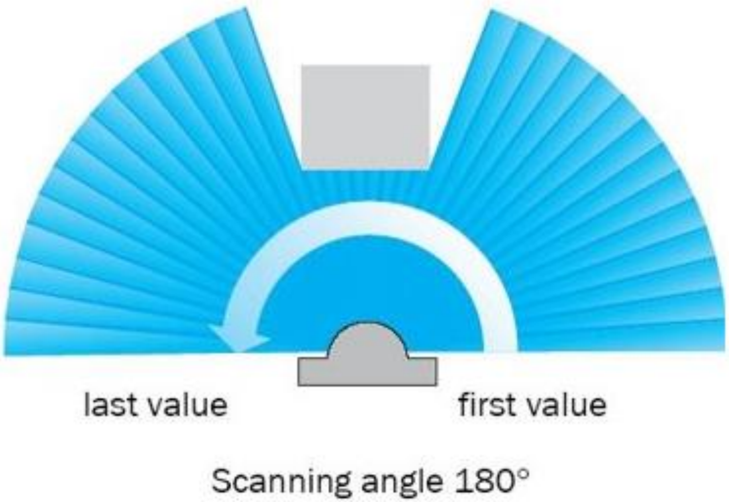
→ in theory, we can repeat it 3 millions times / second.

→ Let's put it in context again: a camera of 3 megapixels can give the 3 millions reads @ a rate of 30 times /second (30*3millions/sec).

→ But a rgb camera cannot give range.

2D LIDAR

Here, a 2D LiDAR scanning 180 degrees (FoV = 180°), in a plane



The laser beam is pulsed periodically,
at different directions (in its azimuth).

This is usually done by using a rotating
mirror to deflect the emitted beam to the desired directions.

There is a good number of different brands and models

Typical FoV: ,100°,180°, 270° , and also 360°; depending on brand/model, and mode of operation chosen)

Angular Resolution:

In addition to the FoV, the angular resolution is a relevant parameter.

Usual resolutions : 1º, 0.5º, 0.33º, 0.25º, 0.1º

The one we will see soon in the lecture, operates at 0.33º (3 beams / degree)

WORKING MECHANISM

LiDARs are “Active” sensors.

Advantage: Do not require external illumination (as a camera would need)

Disadvantage: may interfere with other active sensors operating in the same range of wavelengths.

It may need to compete with natural sources of light in the same IR spectrum range (sun)

Limitations

LiDAR are based on light to see objects, which may result in:

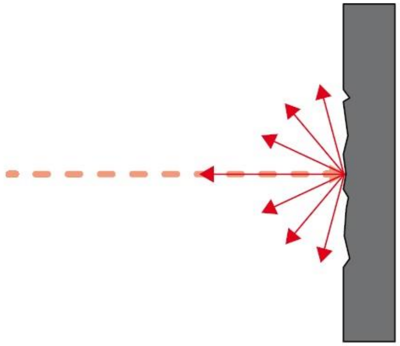
It may need to compete with natural sources of light in the same IR spectrum range (sun)

Occlusions , as IR light suffers effects like visible light (radars would not)

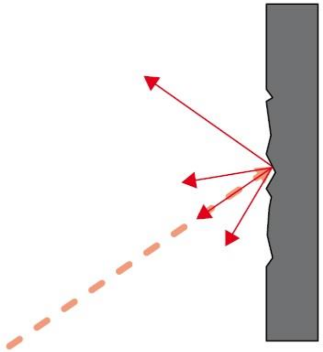
Environmental conditions (dust pollution, fog, rain)

LIMITATIONS

Effect on reflected light, due to surface characteristics

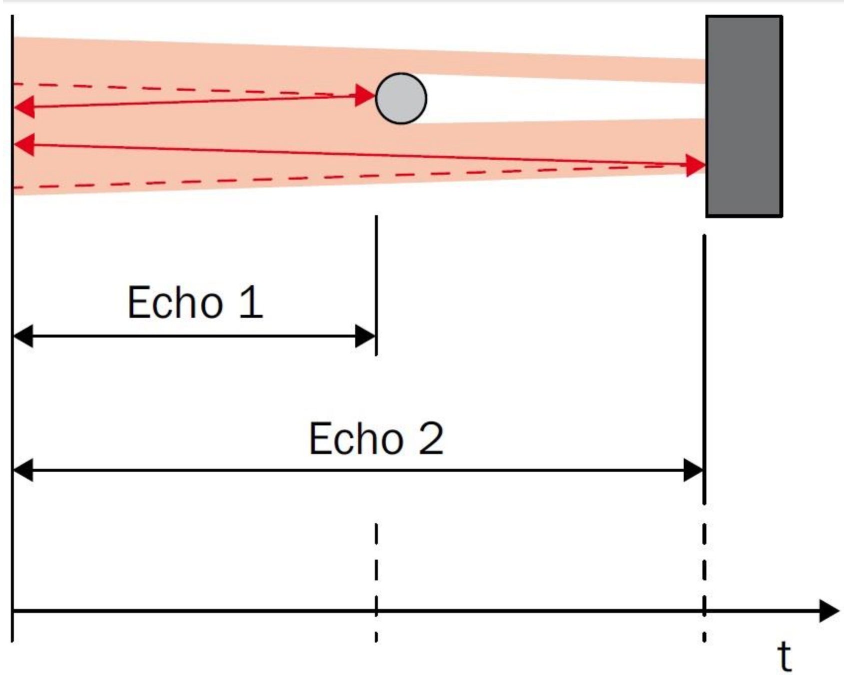


Not all the surfaces are good reflecting light in the incidence direction.
(if not enough energy is returned to the sensor, no pulse detection will occur)



LIMITATIONS

Multiple echoes

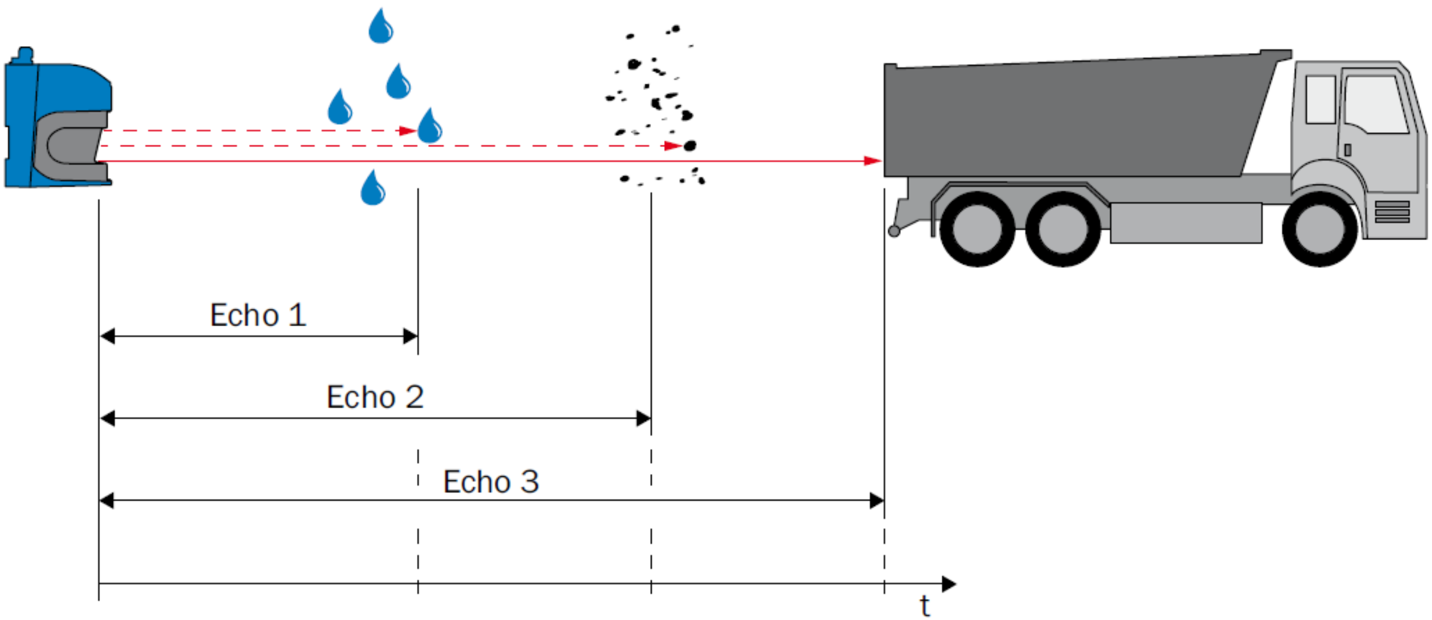


The laser beam is not a line of infinitesimal section. It has certain thickness (which increases with the travelled distance, due to laser divergence)

The beam may partially hit multiple surfaces , resulting in multiple echoes
(proper processing may see a benefit in that!)

LIMITATIONS

Multi-Echo due to environmental conditions (rain, fog, dust in suspension)



Those allow transmission, however producing more attenuation of the light (reducing maximum range of detection) and also generating additional reflections with result in echoes.

(image from https://www.sick.com/au/en/detection-and-ranging-solutions/2d-lidar-sen)

LIMITATIONS

→ Resolution is angular.

The size of the beam, and the (linear) density of points (points/meter) varies as a function of the distance, *dS = da*pi/180*Range*

In which ***da*** is the angular resolution (expressed in degrees, da=1 degree or 0.5 degrees or 0.25 degrees)

Higher angular resolutions are offered, but those are achieved by "interleaving" , which means that multiple consecutive scans are performed having the max real resolution (e.g. 0.25 degrees) and having small shifts between scans (e.g. 0.25/2), so that 2 scans combined achieve 0.25/2 of resolution.

This is usually OK when both, sensor and objects, are static.

REFLECTIVITY

Different materials have different reflectivity, which may generate issues.

- Highly reflective surfaces may saturate some laser detectors. Some dark/opaque surfaces may absorb too much of the light, resulting in reflections that are not intense enough to be measured by the detector.
- Minimum detectable object size depends on reflectivity (narrow but highly reflective could still reflect enough energy to be detected)
- A strong sunlight reflection off a highly reflective areas may "saturate" a receiver, affecting its performance.
- Reflectivity of scanned surfaces affects maximum range of the sensor.

REFLECTIVITY

Here, we can see a table which describes reflectivity indexes of typical materials.

(from maker of industrial LiDARs, RIEGL)

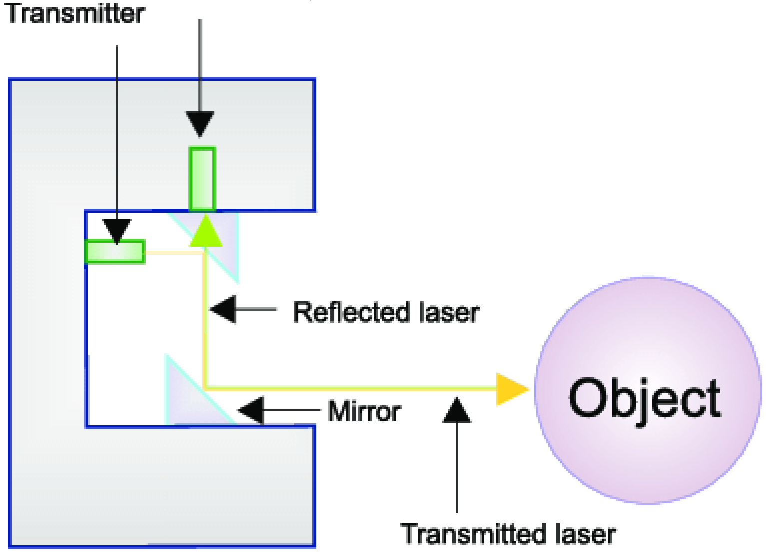
MATERIAL	REFLECTIVITY @ λ = 900 nm
Dimension lumber (pine, clean, dry)	94%
Snow	80-90%
White masonry	85%
Limestone, clay	up to 75%
Deciduous trees	typ. 60%
Coniferous trees	typ. 30%
Carbonate sand (dry)	57%
Carbonate sand (wet)	41%
Beach sands, bare areas in desert	typ. 50%
Rough wood pallet (clean)	25%
Concrete, smooth	24%
Asphalt with pebbles	17%
Lava	8%
Black rubber tire wall	2%

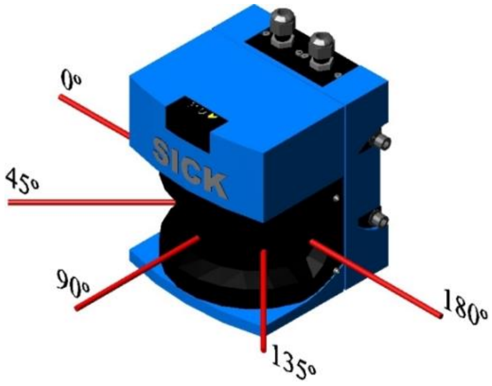
Source: www.riegl.co.at

DUST, SMOKE, VAPOR, RAIN?

- Laser measurements can be degraded by interacting with vapor and also with dust and smoke particles, which scatter the laser beam, and do also attenuate he signal returned from the target.
- Using “last-pulse” measurements can mitigate certain problems with this interference (emitted pulse results in multiple reflections, so that the last one is assumed to be the “real one”)
- Systems that are expected to work in such conditions regularly can be optimized for these environments (in addition certain processing techniques which allow to properly extract information of the polluted/distorted measurements; such as Bayesian estimation, CNN, etc.)

EXAMPLE: 2D SICK LMS 200 (A CLASSIC!)





https://www.sick.com/au/en/detection-and-ranging-solutions/2d-lidar-sensors/lms2xx/lms200-30106/p/p109843

Many variants
Industrial grade

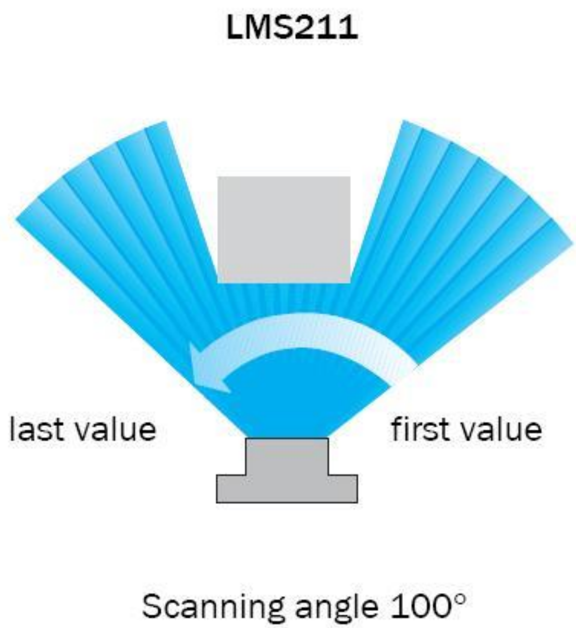
Example: LMS 200 family

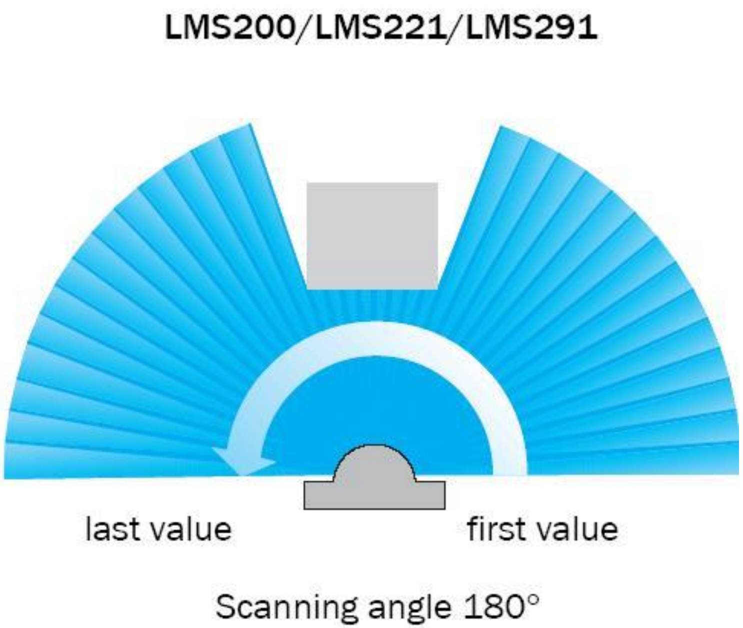
- Range ~ 80 meters
- Resolution : 1 cm
- Angular range : 100 - 180 degrees
- Angular resolution : 0.25, 0.5 or 1 degrees
- Scan time : Typical = 13.5 milliseconds (~74 fps)(*).

LMS200 LMS211 LMS221 LMS291

There are other models/brands that offer better angular resolution and more range.

(*) E.g. it scans 180 degrees, at a resolution of 1 degree in 13.5ms.





(we see a demonstration in class , small LMS TIM, (FoV) = 225 degrees)

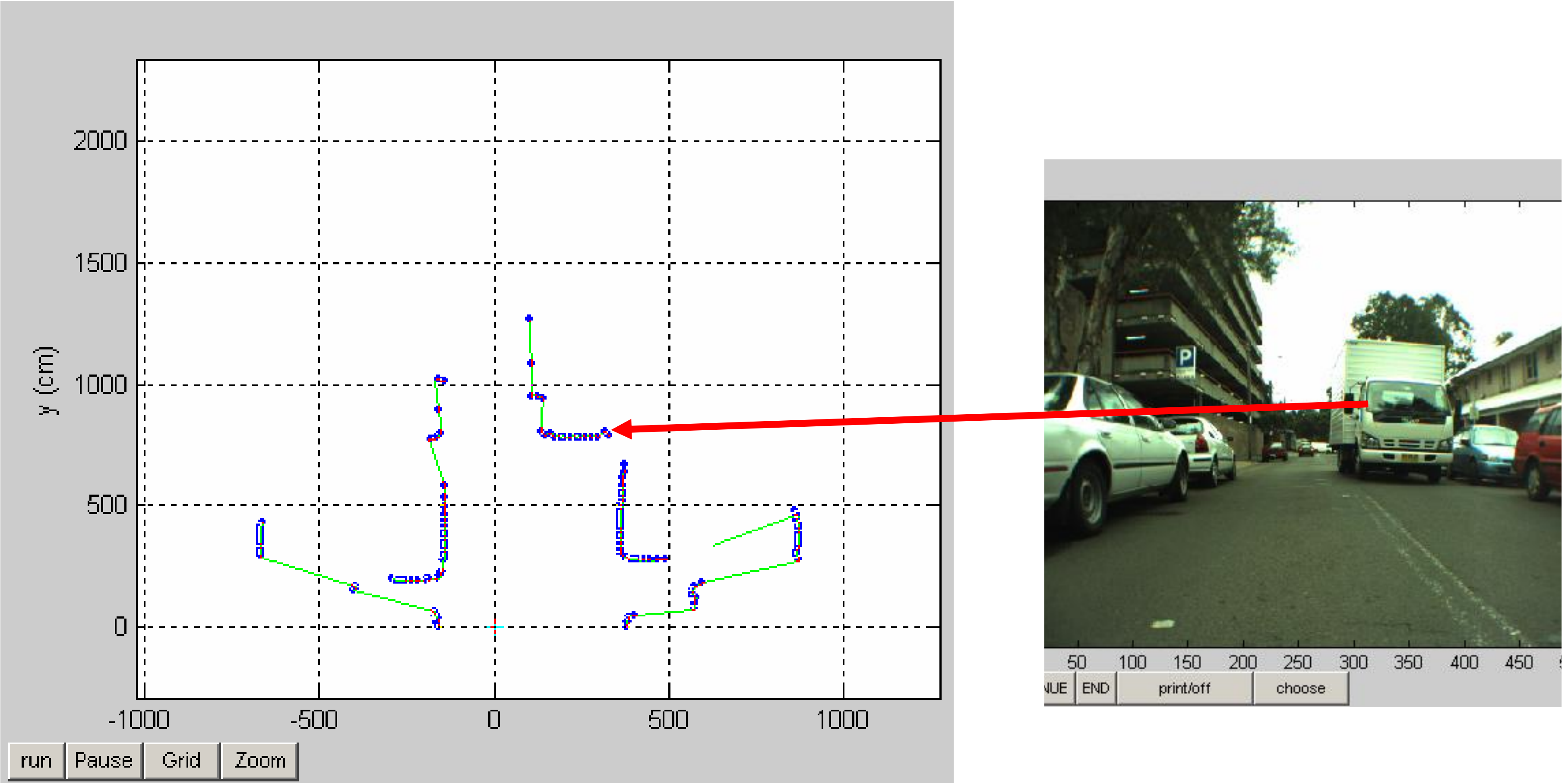
Industrial grade.

Can work in harsh contexts
(e.g. mining)

(lecturer had experience using them in
those contexts)

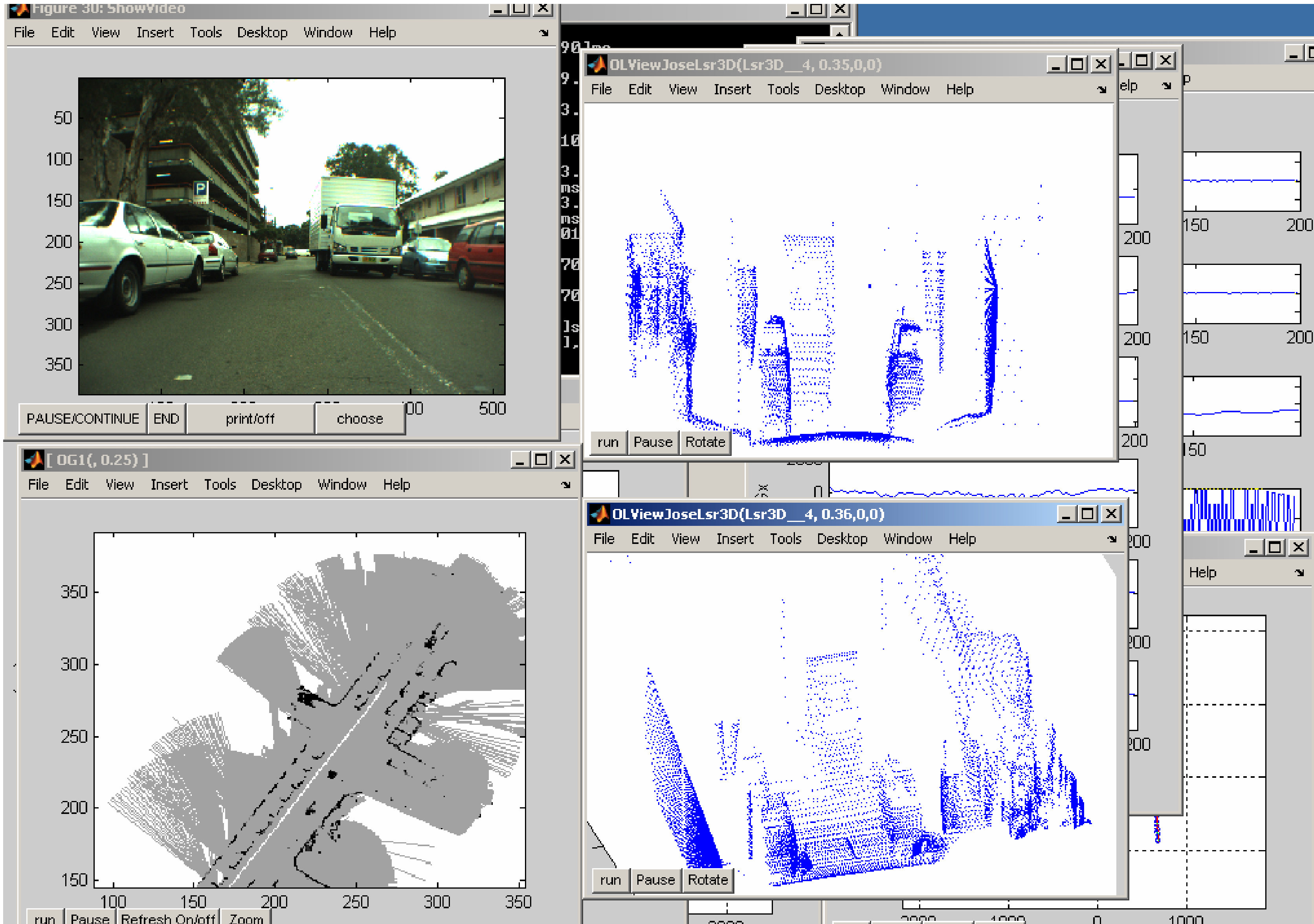
Laser scanner installed as part
of collision avoidance system.

… as part of truck guidance system.



A 2D laser scan and its associated video image (from a video camera)
The sensors were installed at the front of a vehicle
(for a collision avoidance system)

By combining multiple scans, from different perspectives, mapping and 3D images can be obtained.
(these fusion processes require applying C.F. transformations!)



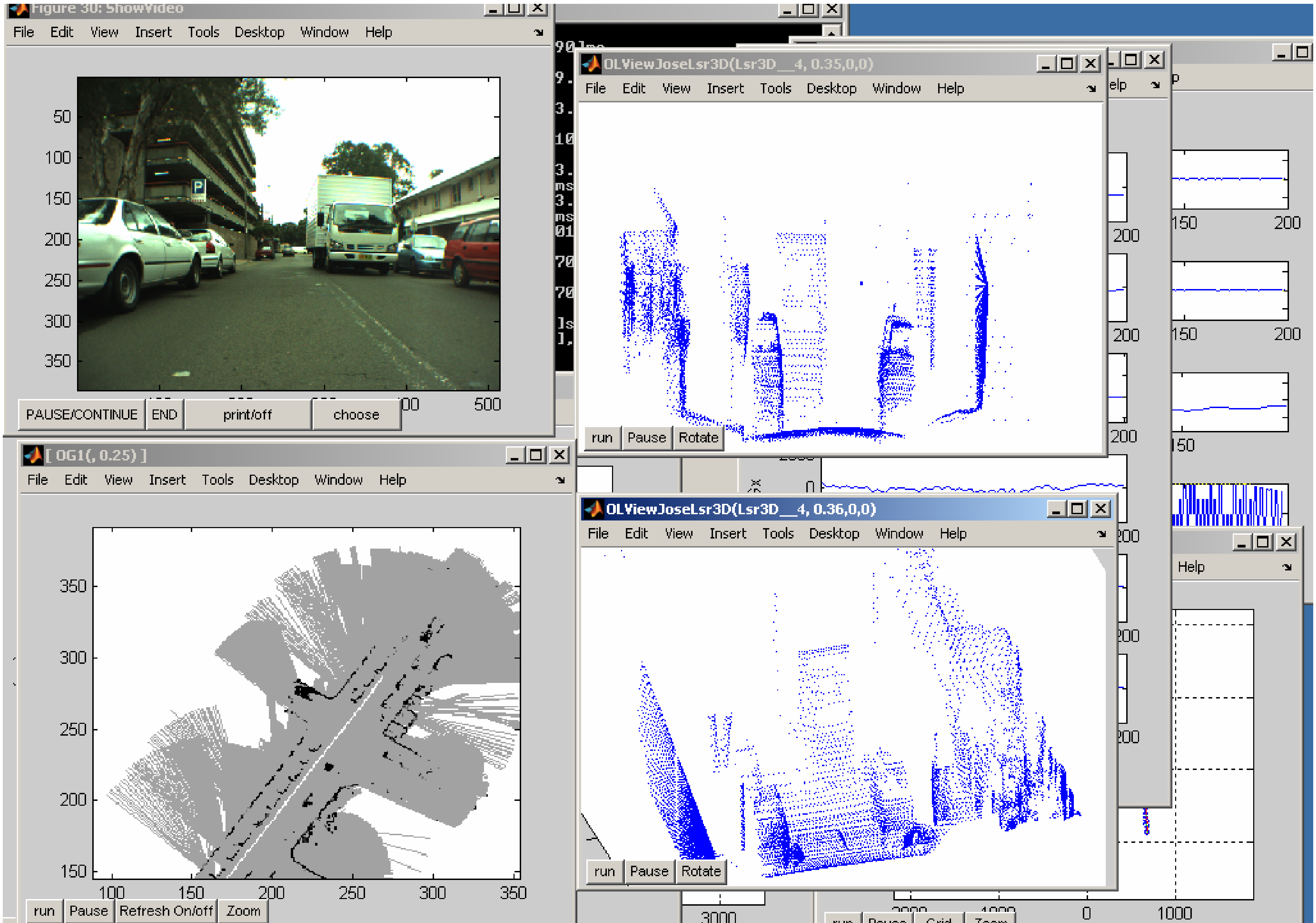


Figure 30: ShowVideo
File Edit View Insert Tools Desktop Window Help
PAUSE/CONTINUE
END
print/off
choose
OLViewJoseLsr3D(Lsr3D__4, 0.35,0,0)
File Edit View Insert Tools Desktop Window Help
run
Pause
Rotate
[OG1(, 0.25)]
File Edit View Insert Tools Desktop Window Help
run
Pause
Refresh On/off
Zoom
OLViewJoseLsr3D(Lsr3D__4, 0.36,0,0)
File Edit View Insert Tools Desktop Window Help
run
Pause
Rotate
run
Pause
Grid
Zoom

EXAMPLE IN OUR LECTURE: 2D SICK TIM

(WE SEE IT WORKING)

TIM561-2050101S80 | Part no.: 1106065

2D LiDAR sensors | TiM5xx

- **Application:** Outdoor
- **Integrated application:** Output of measurement data
- **Measurement principle:** HDDM
- **Working range:** 0.05 m ... 10 m
- **Angular resolution:** 0.33°
- **Digital outputs:** 1 (PNP, SYNC/device ready)
- **Connection type:** 1 x “Ethernet” connection, 4-pin M12 female connector, 1 x connection “Power/Synchronization output” 5-pin, M12 male connector, 1 x Micro USB female connector, type B

(HDDM: High Definition Distance Measurement = ToF approach)

Model 571 has range =25m
FoV=270 degrees.

https://www.sick.com/au/en/detection-and-ranging-solutions/2d-lidar-sensors/tim5xx/c/g292754

Let’s see some LiDAR working , now.

(I have now a SICK TIM 541.)

Typical data.

The sensor has a communication protocol , used to read its measurements and for sending commands to the sensor.

We are not concerned with accessing the sensor directly (you did that in MTRN3500). Our interest is about processing those measurements.

Our processing modules are called to do some processing, being given the measurements.

Your functions (which you will implement in the projects) will be called in that way.

Usually, the measurement involve some “explicit “ component, and also some “implicit” one.

As the sensor scans at regular angles, and covers a defined FoV, those parameters are known a priory, so that the measurement does not include those values.

The measurement are the “ranges”. So, if the FoV is 180 degrees and the sensor does scan every ½ degree. From -90 to +90, it will provide 361 ranges

For angles [-90, -89.5, -89, ………-0.5,0,+0.5, ………89, 89.5, 90]

Because that, the sensor simply sends the361 ranges associated to those 361 directions.

Ranges are usually expressed as unsigned integer numbers of certain number of bits.

For this model, it uses 16 bits. Each count represent a small distance, which is the range resolution. It is also affected by how the sensor is configured.

We consider the case in which 1 count is 1 mm.

So that, for instance, a range =1234 would mean 1.234 meter (1234mm).

% rangesA[] is an array of size 1x361, of class uint16 (native representation),

r= single(rangesA)*0.001

% now we have the ranges expressed in meters, in single precision

(an array of 361) single precision numbers. Those values are scaled to meters.

What would be their associated angles?

a = [-90:0.5:90]* pi/180 ; % 361 angles, from -90 to 90 in steps of ½ degree; expressed in radians.

We need to generate this array just once, as it is a “constant”

POLAR , cartesian?

We use what is more convenient to us. Usually cartesian (but not always).

The expression to obtain the scanned points but in cartesian would be

```
p(i)    = [ r(i)*cos( a(i) ); r(i)*sin( a(i) )];  % for each I from 1 to 361
```
% this may be similar but different, depending in the axis convention you use.

However some ranges may be invalid, because no reflexion did occur in that direction. In those cases, the sensor will report certain “flag” in that range.

Suppose we know that range values =0 or higher than 50000 are invalid.

So we detect those invalid ine, before trying to obtain the points.

```
 ii =find ( (rangesA==0)||(rangesA>50000));
r= single(rangesA(ii))*0.001;
a2 = a(ii);
```

Both arrays , r and a2 will have numel(ii) elements, which could be lower than 361.

This is usual, as many ranges may be invalid (no reflexion)

In the tutorial problems, on week 1, we use simulated LiDAR data, which have FoV [-80 r to 80 degrees, with angular resolution =½, degrees, resulting in scans of 321 ranges.

Let’s go to Matlab now, to see problem 4 of the tutorial, in which we need to play with some of those simulated LiDAR scans.

First I show you, how was that obtained using the simulator program (which you will use later in some parts of the project/tutorial)

(we end this topic here)