Water and liquid level measurement using VL53L5CX Time-of-Flight 8x8 multizone sensor with wide field of view

Introduction

This document describes how a user can design a system to detect the level of a container of water or other clear liquid, using the VL53L5CX multizone Time-of-Flight (ToF) sensor with wide field of view.

The ST FlightSense ToF sensors work by emitting a pulsed cone of light, which hits the target and bounces back. The sensor detects the returning signal and measures the photon travel time. The travel time divided by two and multiplied by the speed of light gives the distance. In most cases, this is a very robust system.

In this application note, the VL53L5CX ToF sensor is used to measure the level of water in a container.

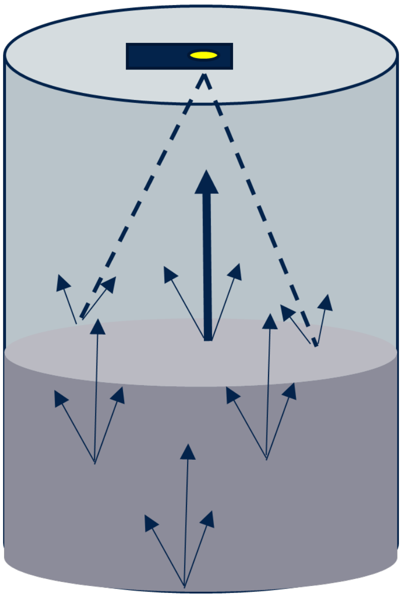
Background

The VL53L5CX allows multi-zone distance measurements with up to 8x8 real time native zones and a wide 63° diagonal field of view. Each zone of the sensor can measure the distance to a target at up to 4 meters with a maximum frequency of 60 Hz. With ST’s patented histogram algorithms, the VL53L5CX is able to detect multiple objects within the FoV and ensures immunity to cover glass crosstalk beyond 60 cm.

1 Observations on water

Water is a particular case. Some photons hit the surface and reflect. Some photons are absorbed by the water. Some photons penetrate the water, hit the bottom, and are reflected back. Those photons are slowed significantly by the water.

Figure 1. **Different return paths of photons on water**



The distance from the sensor to the water can be estimated by averaging all those photon timings, but it would only be a rough estimate.

Another consideration is the surface condition of the water. Turbid (dirty) water seems to reflect far more photons from the surface, which provides a good measurement. Likewise, agitated water or water with lots of bubbles also returns a large number of photons from the surface, which allows accurate measurement.

It is still water that is a problem. Still water acts like a specular (mirror-like) surface. Turbid, moving, or foaming water can be characterized as Lambertian (non-mirror like or matte finish).

The issue is how to differentiate between the types of water.

2 VL53L5CX graphical user interface data

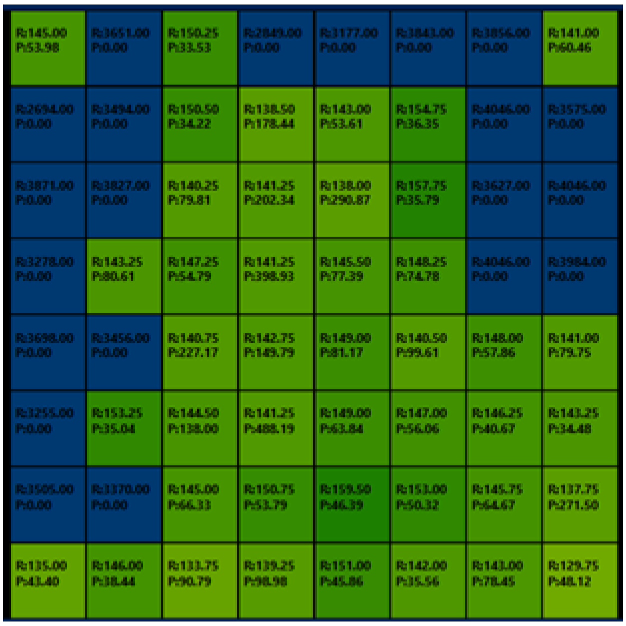
Consider this data gathered using the VL53L5CX evaluation kit sensor looking down on bowl of water from a distance of 140 mm. The R is the range data, or distance to the object in milimeters. The P is the power of the return signal in mega counts per second.

This clear water is so reflective that only the center zones return a signal at all. The light from the outer zones simply bounces off.

Figure 2. Still water at range = 140 mm. Signal return P = 920

Agitating the water produces a quite different picture.

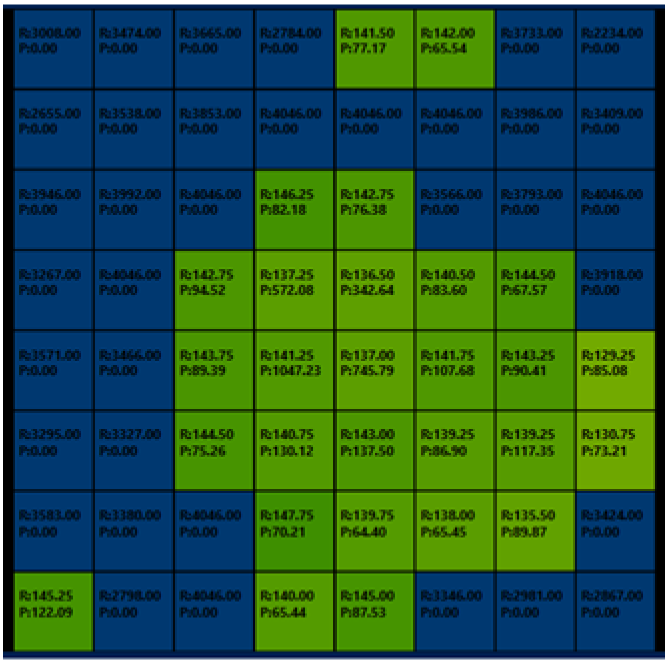
Figure 3. Agitated water at 140 mm



In the figure above the agitated water returns a signal from many zones, and the distances are all accurate although there is quite a bit of variation due to the waves. Some zones still return no signal.

Sprinkling a bit of chocolate powder into the water simulating turbidity produces a very similar plot to the agitated water.

Figure 4. **Turbid (dirty) water**



Note that the most reliable numbers come from those zones with the largest signal. On average, they are all relatively accurate.

3 Container properties

The following was taken at a height of 140 mm. The container was a glass dish with 15 mm of water in it, placed on a reflective polished surface.

Figure 5. Still water in a glass dish

The 142.75 distance is pretty accurate (140 would have been exact) but there is some influence from the glass bottom reflectivity. The other zones are clearly more affected as none of those numbers show the distance to the water. They are much closer to the distance to the table on which the dish is set.

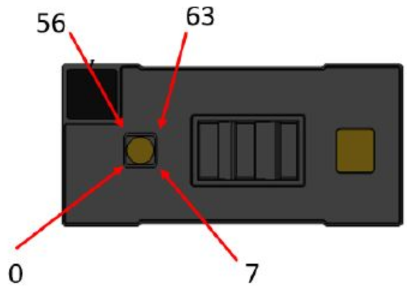
4 Description of the experiment

4.1 Measurement principle

The 12 center zones of the array (19, 20, 26, 27, 28, 29, 34, 35, 36, 37, 43, 44), also called zones of interest, are used to estimate the level of the water.

Figure 6. **Measurement zone**

56	57	58	59	60	61	62	63
48	49	50	51	52	53	54	55
40	41	42	**43**	**44**	45	46	47
32	33	**34**	**35**	**36**	**37**	38	39
24	25	**26**	**27**	**28**	**29**	30	31
16	17	18	**19**	**20**	21	22	23
8	9	10	11	12	13	14	15
0	1	2	3	4	5	6	7



4.2 HW required

To duplicate this experiment, a VL53L5CX Nucleo expansion board (X-NUCLEO-53L5A1) is required with a NUCLEO-F401RE Nucleo board. These two boards are also available as a kit under P-NUCLEO-53L5A1.

You can also contact your ST sales representative.

4.3 Pseudo code

The pseudo code is straight forward.

```
Take a range.
Extract the signal strength and distance data from all zones of interest.
Examine the signal strengths of those zones with valid data.
If all the strengths are of the same magnitude, {
    The surface is Lambertian and all the distances will be fine.
}
If one or two signal strengths is far greater than its neighbors {
    The surface is specular.
    Return the distance from the zone with the largest signal return.
}
```

4.4 The function

The following function is part of the example code available on st.com under the reference STSW-IMG039_L5CX. This example code is a C code working with the STM32CubeIDE.

```
int liquid_detect(
    VL53L5CX_ResultsData *range, int Sensor_height, int *liquid_height)
{
/* center zone locations:
* 19,20
* 26,27,28,29
* 34,35,36,37
* 43,44
*/

  int search_zones[12] = {27,28,35,36,19,20,26,29,34,37,43,44}; //center zones
  int i, idx, status, distance, r_signal, targets=0;
  int max_signal = 0;
  for (i=0; i<12; i++){
    idx = search_zones[i];
    status = range->target_status[VL53L5CX_NB_TARGET_PER_ZONE*idx];
    distance = range->distance_mm[VL53L5CX_NB_TARGET_PER_ZONE*idx];
    r_signal = range->signal_per_spad[VL53L5CX_NB_TARGET_PER_ZONE*idx];
    targets = range->nb_target_detected[VL53L5CX_NB_TARGET_PER_ZONE*idx];
    if(targets>0 && (status == 5 || status == 6 || status == 9))
      {
        if((r_signal ) > max_signal) {
          max_signal = r_signal;
          *liquid_height = Sensor_height - distance;
        }
      }
  }
  return 0;
}
```

Function parameters

*range is the structure returned by the sensor.

Sensor_height is the distance from the sensor to the bottom of the container.

*liquid_height is the height of the liquid from the bottom of the container.

Notes:

1. This function returns the distance from the base to the target. To calculate that one enters the distance from the sensor to the base.
2. There are 64 zones, but the liquid level monitoring is limited to the 12 center zones in this example. The reason for the strange order is to easily limit the search to the four center zones – if desired.
3. A range is considered valid if its status = 5, 6, 9 or 12.

5 Known issues

ST has identified the following known issues:

1. Container reflectivity. If the container bottom is particularly reflective, the results are not accurate until there is a significant depth of liquid. A stainless-steel mug exhibits this issue.
2. Container size. The zones of the VL53L5CX can be influenced by any of the following: the cup lip, the base on which the cup sits, and the depth of the water. A particularly small container, such as an espresso cup may not have a zone where only the water is observed.

Revision history

Table 1. Document revision history

Date	Version	Changes
14-Oct-2022	1	Initial release

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