Liquid Level Monitoring using ST Time-of-Flight technology

STMicroelectronics
Agenda

1. Liquid level monitoring principle & core Key Performance Indicators
2. ST Solutions and benefits
3. Markets & Applications
4. Support package
Liquid level monitoring principles
Liquid level: The half-full half-empty question

- **Liquid level monitoring**
  - A widespread use-case, present in multiple applications & markets
  - To monitor welcomed liquid, or unwanted liquid to be disposed of
  - A liquid cannot be considered in isolation from its container. Liquid volume is a real time adequation between the container and liquid within the overall system

- **An age-old challenge**
  - From 3000-year-old technologies to daring deployment of the most modern technologies and applied technics

- **Two main liquid level monitoring categories**
  - Point-level measurement
    - 100%
    - 80%
    - 60%
    - 40%
    - 20%
  - Continuous level measurement
    - 78%
    - 43%
Liquid level Monitoring Core KPIs

KPIs may differ, from those in high safety industrial applications to less stringent consumer systems needs.

- Improved reading reliability and liquid volume projections
- Safety improvement
- Cost savings
- User satisfaction
- Contamination risks reduction
- Greener materials
- Power consumption reduction
- Industrial design integration flexibility
ST Solutions and benefits
**FlightSense™** introduction

... Making Light work

**Time-of-Flight Principle**

- **ST proprietary FlightSense™ technology**
- True distance measurement
  - Independent of target size, color & reflectance
- Fast and low power
- Truly invisible 940nm illumination
All-in-one optical modules

All-in-One (illumination & sensor) Time of Flight System → Optimized Size, performance, cost mix

- ToF Pixel Expertise
  SPAD/FPD
- Advanced Photonics
  CMOS Process
  (40nm/3D)
- Micro-Optics
  & Supply Chain
- Illumination Expertise
  & Supply-chain
- Embedded ToF
  Processing
  & Depth ISP
- Advanced Packaging
  know-how
  & manufacturing
- Monolithic ToF SoC,
  SPAD Array,
  RAM/ROM & high safety Class1 VCSEL driver
- Advanced optics with integrated IR filters
- State-of-art assembly & testing
  ST manufacturing line in Shenzhen
- Full Class 1 safety
  high efficiency VCSEL
Improving liquid level monitoring

What exists

- **Point level Measurements**
  - 100% • Conductivity
  - 80% • Float switch
  - 60% • Rotating paddle
  - 40% • Vibrating (tuning fork)
  - 20% •

- **Continuous level Measurements**
  - 78% • Capacitance
  - 43% • Optical (Laser, LED)
  - • Cable base (yo-yo)
  - • Ultrasound
  - • Radar (microwave)

Two ST Solutions

- **Single-zone ToF sensors**
- **Multi-zone ToF sensors**

Core Benefits

- **Not “intrusive”**
  - No moving part offering high reliability
    - Contactless
    - No physical part in contact with liquid
    - No risk of contamination
    - Non-ecology friendly materials free
  - Cost saving
    - BOM, operational time, maintenance

- **Works with all liquids**
  - Water, fuel, oil...

- **Small size**
  - Compatible with challenging industrial designs
  - Easy to retrofit in existing systems
VL53L4CD vs VL53L5CX

A dual throng solution portfolio for best end-system integration adequation

**VL53L4CD – High accuracy proximity sensor**

- Single-zone sensor
- Narrow 18° FoV
- Max distance ranging: 130cm
- Very high-performance proximity sensor
- Ambient light immunity: 60cm (under 5Klux)
- Fast ranging frequency (up to 100Hz)
- Easy to use UltraLite Driver

**VL53L5CX – First multi-zone ToF sensor**

- Parallel multi-zone ranging output (4x4 or 8x8)
- Wide FoV: 45° x 45° (63° diagonal)
- Up to 400 cm ranging
- Immunity to cover glass cross-talk beyond 60cm
- Autonomous mode available (down to 1.3mA)
- High ambient immunity: 170cm (under 5Klux)
- 60Hz (4x4 zones) frame rate capability

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Package size : 4.4 x 2.4 x 1 mm
FoV : 18°
Single zone

Package size : 6.4 x 3.0 x 1.5 mm
Square FoV : 45° x 45° (63° diagonal)
Multi-zone (8x8)
VL53L5CX multi-zones solution

VL53L5CX liquid level monitoring solution uses 12 perpendicular center zones

Step 1 – Extract signal strength and distance from center zones

Step 2 – Take the highest signal strength zone

Step 3 – Extract the distance of this zone
VL53L4CD single-zone solution

VL53L4CD Liquid Level Monitoring solution characterization & preset process

Step 1 – Characterize your setup conditions

<table>
<thead>
<tr>
<th>Step</th>
<th>Expected</th>
<th>Offset</th>
</tr>
</thead>
<tbody>
<tr>
<td>100%</td>
<td>42mm</td>
<td>+15mm</td>
</tr>
<tr>
<td>80%</td>
<td>84mm</td>
<td>+8mm</td>
</tr>
<tr>
<td>60%</td>
<td>126mm</td>
<td>±2mm</td>
</tr>
<tr>
<td>40%</td>
<td>168mm</td>
<td>±3mm</td>
</tr>
<tr>
<td>20%</td>
<td>204mm</td>
<td>-16mm</td>
</tr>
<tr>
<td>0%</td>
<td>234mm</td>
<td>-12mm</td>
</tr>
</tbody>
</table>

Step 2 – Apply the ST algorithms

<table>
<thead>
<tr>
<th>Step</th>
<th>Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>100%</td>
<td>High deviation</td>
</tr>
<tr>
<td>80%</td>
<td>Apply offset value</td>
</tr>
<tr>
<td>60%</td>
<td>Low deviation</td>
</tr>
<tr>
<td>40%</td>
<td>Take measure as it</td>
</tr>
<tr>
<td>20%</td>
<td>High deviation</td>
</tr>
<tr>
<td>0%</td>
<td>Apply offset value</td>
</tr>
</tbody>
</table>

Step 3 – Measure the liquid level

<table>
<thead>
<tr>
<th>Step</th>
<th>Measured</th>
<th>Real</th>
</tr>
</thead>
<tbody>
<tr>
<td>100%</td>
<td>Example 1</td>
<td>High dev. 110mm</td>
</tr>
<tr>
<td>80%</td>
<td>Example 1 102mm</td>
<td>110mm</td>
</tr>
<tr>
<td>60%</td>
<td>Example 2 151mm</td>
<td>Low dev. 151mm</td>
</tr>
<tr>
<td>40%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Live demo using VL53L5CX
# FlightSense Benefits

<table>
<thead>
<tr>
<th>Not “intrusive”</th>
<th>Small size</th>
<th>Cost Saving</th>
<th>Works with all type of liquids</th>
<th>Connected</th>
</tr>
</thead>
</table>
| • No moving parts, offering high reliability  
• Contactless  
• No physical part in contact with liquid  
• No risk of contamination (drinking water, milk)  
• Non-ecology friendly materials free (Neodyme for example) | • Compatible with challenging industrial designs  
• Easy to retrofit in existing systems & invisible illumination | • No moving parts saving BOM  
• Increase of the operational time  
• Reduced maintenance costs | • Water  
• Fuel  
• Oil  
• Milk  
• Coffee  
• Juice  
• … | • Monitoring in real-time |

## Not “intrusive” Features
- No moving parts, offering high reliability
- Contactless
- No physical part in contact with liquid
- No risk of contamination (drinking water, milk)
- Non-ecology friendly materials free (Neodyme for example)

## Small Size Features
- Compatible with challenging industrial designs
- Easy to retrofit in existing systems & invisible illumination

## Cost Saving Features
- No moving parts saving BOM
- Increase of the operational time
- Reduced maintenance costs

## Works with all type of liquids
- Water
- Fuel
- Oil
- Milk
- Coffee
- Juice
- …

## Connected Features
- Monitoring in real-time
Markets & Applications
Real time liquid level measurement allowing end user to anticipate replenishment

<table>
<thead>
<tr>
<th>Coffee machine</th>
<th>Smart bottle</th>
<th>Steam iron</th>
<th>Other applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiple use-cases using ST Time-of-Flight sensors:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Water level monitoring</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Empty capsule container control</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Coffee cup shape identification</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Smart water bottle liquid level

Steam iron remaining water level

• Water level monitoring
• Empty capsule container control
• Coffee cup shape identification
Real time liquid level monitoring enabling efficient replenishment cycle & enhanced user satisfaction

- **Soap dispensers**: Real time stock management enabling efficient replenishment cycle and user satisfaction
- **Smart toilets (flush)**: Reduce system corrosion risk
- **Cosmetic containers**: Cosmetic containers liquid level
Combine liquid level monitoring with other ST ToF enabled use-cases

Home automation and Smart building

Beverage dispenser

ST released a video presenting all applications for a beverage dispenser:
• Liquid level monitoring
• Gesture recognition
• Cup detection

Rainwater tank

Home rainwater tank liquid level

0.1-3m

Other applications

Smart pet feeder

Pet feeder water level

0 - 30 cm
ST ToF solutions addressing multiple applications in the diversified Industrial market

**Oil tank**
Home oil tank level

**Storage tank**
Industrial storage tank liquid level

**Medical**
Transfusion bag or smart breast pump liquid level monitoring

**Other applications**
Smart Farming

Unlimited markets, ST ToF solutions supporting smart-farming for cattle satisfaction & beyond

- **Milking machine**
  - Milk machine liquid level
  - 0.1 – 1m

- **Drinking trough**
  - Drinking trough liquid level
  - 25 cm

- **Water tower**
  - Water tower liquid level
  - 0.1 – 4m
Support package
• Evaluation boards available
• Software package:
  • CubeIDE projects
  • Characterization tool (for VL53L4CD only)
  • Source code
• Technical documentation:
  • Application Notes
  • User Manual

<table>
<thead>
<tr>
<th></th>
<th>VL53L4CD</th>
<th>VL53L5CX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Software code</td>
<td>STSW-IMG039_L4CD</td>
<td>STSW-IMG039_L5CX</td>
</tr>
<tr>
<td>Application Note</td>
<td>AN5851</td>
<td>AN5843</td>
</tr>
<tr>
<td>Evaluation boards</td>
<td>X-NUCLEO-53L4A1</td>
<td>X-NUCLEO-53L5A1</td>
</tr>
<tr>
<td></td>
<td>P-NUCLEO-53L4A1</td>
<td>P-NUCLEO-53L5A1</td>
</tr>
<tr>
<td></td>
<td>SATEL-VL53L4CD</td>
<td>VL53L5CX-SATEL</td>
</tr>
</tbody>
</table>

* Standard, widely available product related boards and tools
VL53L5CX multizone solution

**VL53L5CX Liquid Level Monitoring solution provides highly accurate measurement**

**Step 1 – Prepare your monitoring**
- Take VL53L5CX 12 center zones as displayed
- Center zones must cover the water and not the tank sides

**Step 2 – Liquid level measurement**
- Take highest signal rate center zone
- Extract this zone distance
- To obtain liquid level, subtract measured distance from container height

**FoV covers tank sides**

**FoV does not cover tank sides**

Center zones

Full FoV

Container height 100mm

Measured distance 90mm

Software reference: STSW-IMG039_L5CX

Application Note AN5843

23
Step by step VL53L4CD Liquid Level Monitoring solution implementation

**Step 1 – Use the characterization tool**

- Define liquid level indicator count
- For each characterization (min = 4), measure liquid level for each indicator
- Characterization tool creates a lookup table of which offset to apply per level indicator
- Define which zones to apply offset to be integrated in system algorithm

<table>
<thead>
<tr>
<th>Indicator level</th>
<th>Expected liquid level (mm)</th>
<th>OC_val</th>
</tr>
</thead>
<tbody>
<tr>
<td>C9</td>
<td>21</td>
<td>4</td>
</tr>
<tr>
<td>C8</td>
<td>42</td>
<td>4</td>
</tr>
<tr>
<td>C7</td>
<td>63</td>
<td>2</td>
</tr>
<tr>
<td>C6</td>
<td>84</td>
<td>1.6</td>
</tr>
<tr>
<td>C5</td>
<td>105</td>
<td>4.8</td>
</tr>
<tr>
<td>C4</td>
<td>126</td>
<td>13.5</td>
</tr>
<tr>
<td>C3</td>
<td>147</td>
<td>24.8</td>
</tr>
<tr>
<td>C2</td>
<td>168</td>
<td>30</td>
</tr>
<tr>
<td>C1</td>
<td>189</td>
<td>20.3</td>
</tr>
</tbody>
</table>

**Step 2 – Use the ST algorithm**

- Measure liquid level
- If measurement is non-linear
- Then, apply offset from lookup table to measured distance
- Else, use ranging as is
- To obtain liquid level, subtract measured distance from container height

Software reference: STSW-IMG039_L4CD

Application Note AN5851

VL53L4CD single-zone solution
Support on st.com

www.st.com/en/embedded-software/stsw-img039

Liquid Level Monitoring Code Example using Time-of-Flight sensors

Documentation

Videos

https://bit.ly/3iZSsx1

https://bit.ly/3z7aapN

Liquid Level Monitoring using the L4CD example with STM32CubeIDE

Liquid Level Monitoring using the L5CX example with STM32CubeIDE

Contactless Beverage Dispenser
<table>
<thead>
<tr>
<th>Item</th>
<th>Picture</th>
<th>Commercial Product (= Order Code)</th>
<th>Comments</th>
</tr>
</thead>
</table>
| VL53L4CD sensor                    |         | VL53L4CDV0DH/1                    | Delivery in T&R  
MOQ: 4.5ku  
With protective liner                                                                                                                 |
<p>| VL53L4CD Nucleo™ Expansion board  |         | X-NUCLEO-53L4A1-                  | To go along with STM32F401 Nucleo board. Comes with cover-glass holder, 2x cover-window samples                                           |
| VL53L4CD Breakout boards           |         | SATEL-VL53L4CD                    | 2x Breakout boards delivered                                                                                                            |</p>
<table>
<thead>
<tr>
<th>Item</th>
<th>Picture</th>
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</thead>
<tbody>
<tr>
<td>VL53L5CX sensor</td>
<td></td>
<td>VL53L5CXV0GC/1</td>
<td>Delivery in T&amp;R MOQ: 3.6ku With protective liner</td>
</tr>
<tr>
<td>VL53L5CX Expansion board</td>
<td></td>
<td>X-NUCLEO-53L5A1/</td>
<td>To go along with STM32F401 Nucleo board. Comes with cover-glass holder, cover-window sample, 3x spacers</td>
</tr>
<tr>
<td>STM32F401 NUCLEO</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VL53L5CX Breakout boards</td>
<td></td>
<td>VL53L5CX-SATEL/1</td>
<td>2x Breakout boards delivered</td>
</tr>
</tbody>
</table>
FlightSense™ Summary

**Leader on Direct ToF**

1st

**Two liquid level monitoring solutions**

- Not “intrusive”
- Works with all type of liquids
- Small size

**FlightSense benefits**

**Continuous improvement**

**Unlimited markets & applications**
Our technology starts with You