Time of Flight: Principles, Challenges, and Performance

ST Technology Tour 2017
John Kvam
Agenda

- Time of Flight Principles and Design Choices
- Performance
- Application Examples
- Design Challenges
- Calibration
- Evaluation kit : HW & GUI
- Hardware Considerations
- Development & Support
ToF Principles
Time of Flight Basics

Active illumination system:
- Laser emits light (photons) towards a target
- Light (partially) reflected from the target
- Sensor area determines when light (photons) arrives
- ToF is translated into distance

Distance Value = Photon travel time/2 x by speed of light
Allowing 1mm high resolution (time discrimination of 6.6ps!)

Photon travel time NOT affected by target reflectance
Measured Time is Measured Distance
ToF – Order of Operation

**VCSEL** - Emitter:
Vertical Cavity, Surface Emitting Laser

**SPAD** - Receiver:
Single Photon Avalanche Diode
IR notch filter

Proximity Sensor operation description:

- VCSEL emits a pulse of photons towards a target
- Photons are partially reflected from the target to the SPAD
- The SPAD array generates a small pulse for each detected photon
- Time between initial and received pulse is measured
- Time is converted in distance
**FlightSense™ Technology Advantages**

- True Distance
- Color independent
- Gesture capable
- Fully integrated
- Eye Safe
- Texture independent
Two ways to measure the Time of Flight (ToF):

- In the direct method, the time difference between the emitted pulse, and a received signal.

- In indirect, a continuous modulated sinusoidal light wave is emitted and the phase difference between outgoing and incoming signals is measured.
Single Photon Avalanche Diode- SPAD

• From Wikipedia:

• “SPADs are semiconductor devices based on a p-n junction reverse-biased at a voltage $V_a$ that exceeds breakdown voltage $V_B$ of the junction.”

• The trick is to make them small and low-power.

• ST uses a standard CMOS process
Maximum Measurable Distance

Emitted pulse period = Maximum measurable distance
ToF Performance: Distance, Accuracy, Ranging Rate, and Power Consumption
• Solar spectrum at sea level: AM 1.5 standard

• Outdoor = 5kLux equivalent IR

• Indoor = 0kLux (AM1.5) or NO IR emitting light
## FlightSense™ product benefits

<table>
<thead>
<tr>
<th>Feature</th>
<th>VL6180X</th>
<th>VL53L0X</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance measurement</td>
<td>Proximity up to 40cm (*)</td>
<td>Ranging up to 2 meters (*)</td>
</tr>
<tr>
<td>Performance under strong ambient light</td>
<td>+++</td>
<td></td>
</tr>
<tr>
<td>FoV</td>
<td>25 degrees</td>
<td>25 degrees</td>
</tr>
<tr>
<td>ALS</td>
<td>Yes (0 to 100klux)</td>
<td>No</td>
</tr>
<tr>
<td>Laser emitter (Class 1)</td>
<td>850nm</td>
<td>940nm (no red glow)</td>
</tr>
<tr>
<td>Speed for Distance acquisition</td>
<td>Few ms (*)</td>
<td>up to x2 faster (programmable)</td>
</tr>
<tr>
<td>Accuracy</td>
<td>+/- 10mm (*)</td>
<td>+/-3 % (*)</td>
</tr>
<tr>
<td>Programmable modes</td>
<td>No</td>
<td>3 modes in API</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(High-speed, long distance, high accuracy)</td>
</tr>
<tr>
<td>Small all-in-one module</td>
<td>2.8 x 4.8 x 1 mm</td>
<td>2.4 x 4.4 x 1 mm</td>
</tr>
<tr>
<td>Low power consumption</td>
<td>HW stdby &lt;5uA</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ranging: 20mW (average at 10Hz with 33ms ranging sequence)</td>
<td></td>
</tr>
<tr>
<td>Power supply - functional operating</td>
<td>2.6V to 3V (-0.5 to 3.6V)</td>
<td>2.6V to 3.5V (-0.5 to 3.6V)</td>
</tr>
</tbody>
</table>

(*) Depending on conditions like Ambient light, target reflectance and product settings
VL53L0X Internal Sequencing

- Temperature autocalibration is automatically done when starting
- Timing budget is generally 30ms, then **33Hz**
- MSRC will quit ranging if NO Target is present
- 4x Timing Budget implies 2x accuracy
Application Examples
VL53L0 AF Assist Worldwide Adoption

...250 Million sold and many more to follow

**Flightsense™ Principle**

- Emitter
- Photon
- Target

**Distance**

**Focal length**
Power Saving

• Waking up on target / Presence detection
Reliable User Detection

True distance measurement independent of target size and color allows more reliable detection

Reliable Coin Detection

ToF sensor allows system to detect coin when coin inserted much more reliably than conventional IR solutions. Thus user experience improves from significantly decreased coin re-inserting rate
FlightSense™ benefits versus traditional IR

- FlightSense™ allows to discriminate vertical gesture from horizontal gesture while traditional IR sensor cannot
ToF Sensor Challenges
Light Interferers

Signal
- Returns
- Coupling

Noise
- Crosstalk on reference
- Returns on reference
- Leakage
- Crosstalk on return
- Ambient on Reference
- Ambient on Return

Optical paths
Impact of Surface Finish
Due to distance between VCSEL and SPAD, there is a deadzone where the target can be considered out of FoV.

If two objects are present in the FoV, the measured distance will be a weighted average.
ToF Sensor Offset and Crosstalk Calibrations
Offset Calibration Procedure

• Range Offset Calibration
  • The Offset changes slightly during re-flow
  • Perform the P2P offset calibration at manufacture is recommended.

• Range Offset Calibration Procedure
  • With a known distance D1, typical 10 cm.
  • Range several time to get an averaged distance (avD).
  • Offset = D1 - avD.
  • Store the Offset in the host memory to be program at each device boot.
Crosstalk Calibration

- Crosstalk is induced by the photons reflected by the cover glass.
- The magnitude of the cross talk is dependent on the thickness of glass, material and the air gap
- Crosstalk affects longer range measurements where the reflected photon by the target becomes

Procedure

- With a known D2 (60 cm typical)
- Range several times to get an average
- API software provides the compensation coefficient, which is stored in the host memory to be programmed in the ToF at each system boost.
GUI Explanation – Practical Application
VL53L0X Expansion GUI
VL53L0X Expansion GUI Settings

- GUI Settings Panel
VL53L0X Expansion GUI Calibration

Calibration

Current Status:
- Offset: Calibrated
  - Auto-Calibrated Value: 25.000 mm
- X-Talk Compensation: Calibrated
  - Auto-Calibrated Value: 0.000 mm

Next Action: None Required

To perform Auto-Cal, please apply a WHITE target at a 100mm range, then click 'Auto-Cal'.

To provide manual offset parameter instead, use the 'Range Offset' control to provide input then click 'Manual-Cal'.

Offset Controls:
- Range Offset (mm): [ ] 0.00 25.00 Auto-Cal (mm) [ ]
- Range Offset Cal Height (mm): [ ] 100.00

X-Talk Compensation Controls:
- Signal Rate X-Talk Compensation [ ] 0.0000 0.0000 Auto-Cal [ ]
- Signal X-Talk Cal Height (mm): [ ] 400.00
- X-Talk Auto Meas Timeout (ms): [ ] 60.00 Meas On [ ]
Hardware Description
VL53L0X: Electrical/Mechanical
VL53L0X Development Tools and Technical Support
Let’s Start!

VL53L0X module

- Complete documentation and beginners guide
- API
- Samples available via distributors Worldwide
- Delivered with protective liner

Nucleo pack (EVK)

- PC software interface (GUI) + stand-alone mode (4-digit display)
- Nucleo / Arduino™ compatible
- Available as stand-alone Expansion board, or Nucleo pack
- Source code examples and doc.
- Can accept up to two external VL53L0X satellites

More on [www.st.com/VL53L0X](http://www.st.com/VL53L0X) for support and buy-on-line
Hardware Description

• VL53L0X Evaluation tools are all based on the same hardware pack composed of
  • Nucleo F401RE board
  • X-NUCLEO-53L0A1 Nucleo Expansion board
  • Optional two VL53L0X satellites
  • Several gap spacers and cover glass

• Search for **P-NUCLEO-53L0A1** on st.com to order the pack and get documentation
VL53L0X Nucleo pack
X-NUCLEO-53L0A1 works with STM32F401RE

Arduino Connectors

VL53L0X Ranging sensor

2 connections for external VL53L0X satellites

Cover Glass sample
(PMMA material. Low XTalk)

Cover Glass holder
(Can hold Cover Glass and spacers)

PC GUI interface

Spacers
3 spacers 0.25/0.5/1mm to create various air gaps below CG

Autonomous 4-digit display

Cover Glass holder
(Can hold Cover Glass and spacers)
How to use ToF Satellites

• The ToF expansion board can accept “satellites”, through connectors, or flying wires

• For 2.8V supply application, the satellite board can be separated, in order to use only the “mini PCB”, easier to integrate into a customer device
Install STM32 IDE of Your Choice

- Pre-configured projects are available for
  - IAR: [https://www.iar.com/](https://www.iar.com/)

- Lots of example code – just Google VL53L0X
ToF VL53L0: How to place orders?

Go to [www.st.com/VL53L0x](http://www.st.com/VL53L0x)

<table>
<thead>
<tr>
<th>Product</th>
<th>Order code</th>
</tr>
</thead>
<tbody>
<tr>
<td>VL53L0 proximity sensor</td>
<td>VL53L0CXV0DH/1</td>
</tr>
<tr>
<td>Nucleo VL53L0X Expansion board</td>
<td>X-NUCLEO-53L0A1</td>
</tr>
<tr>
<td>Nucleo Pack: VL53L0X expansion board + STM32F410 “Full features” Nucleo board</td>
<td>P-NUCLEO-53L0X1</td>
</tr>
<tr>
<td>ToF VL53L0 satellite</td>
<td>53L0-SATEL-I2</td>
</tr>
</tbody>
</table>
ToF VL6180: How to place orders?

Go to www.st.com/VL6180X

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<tr>
<th>Product</th>
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</tr>
</thead>
<tbody>
<tr>
<td>VL6180x proximity sensor</td>
<td>VL6180XV0NR/1</td>
</tr>
<tr>
<td>Nucleo VL6180X Expansion board (Gen2)</td>
<td>X-NUCLEO-6180XA1</td>
</tr>
<tr>
<td>Nucleo Pack: VL6180X expansion board + STM32F410 “Full features” Nucleo board</td>
<td>P-NUCLEO-6180X1</td>
</tr>
<tr>
<td>ToF VL6180 Satellites</td>
<td>VL6180X-SATEL</td>
</tr>
</tbody>
</table>
Thank You!
Back up
## ToF vs other Proximity Sensing Technologies

<table>
<thead>
<tr>
<th></th>
<th>Capacitive</th>
<th>Ultra-Sonic</th>
<th>Conventional IR</th>
<th>ST FlightSense™</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Size/Weight</strong></td>
<td>Small/light</td>
<td>2xToF/Heavy</td>
<td>Small/Light</td>
<td>Small/Light</td>
</tr>
<tr>
<td><strong>Mechanical integration</strong></td>
<td>Complex (antenna)</td>
<td>Complex (large module)</td>
<td>Easy (if all-in-one)</td>
<td>Easy (all in one, reflowable)</td>
</tr>
<tr>
<td><strong>Signal Amplitude</strong></td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Real distance output</strong></td>
<td>No</td>
<td>No</td>
<td>No (computed)</td>
<td>Real distance in mm (readable thru i²C)</td>
</tr>
<tr>
<td>Minimum distance</td>
<td>0cm</td>
<td>10cm</td>
<td>0cm</td>
<td>0cm</td>
</tr>
<tr>
<td>Maximum distance</td>
<td>Few cms</td>
<td>Up to 1.5m</td>
<td>20cm</td>
<td>up to 2 meters (1)</td>
</tr>
<tr>
<td><strong>Reliable (Vs objects color and reflectance)</strong></td>
<td>No. May detect target in all directions around antenna</td>
<td>No, impacted</td>
<td>No, impacted</td>
<td>Yes, even black (3%), gloves, …</td>
</tr>
<tr>
<td><strong>Reliable (Vs material finish/roughness)</strong></td>
<td>No. Sensitive to body or object charge</td>
<td>No. Isotropic, impacted by wide Sound</td>
<td>No. Angular dependency</td>
<td>Yes, with angular dependency</td>
</tr>
<tr>
<td>Gesture control Tap vs Swipe</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td></td>
</tr>
</tbody>
</table>

(1) depends on conditions
Laser Consideration

- VCSEL has shorter rise time compared to LED (ps instead of ns)
- VCSEL has a smaller beam than LED (35° instead of 120°)
- VCSEL needs less current for the same efficiency
- VCSEL can detect 6x longer with half the power
- VCSEL spectrum is 10x narrower