3D ToF sensor design and it's application in gesture and object recognition

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September 14-18, 2020
Semiconductor Company driven by System Innovation

WORLDWIDE LEADING PRODUCTS
- Elmos serves the **megatrends** (ADAS, EV...) and **attractive niches** with benchmark innovations
- Leading ICs with **#1 positions** worldwide:
  - Ultrasonic ranging, climate control, gesture recognition, ambient LED light, soon LED rear light

LONG-TERM EXPERIENCE IN ICs
- **Founded in 1984** in Dortmund (Germany), **IPO 1999**
- Broad expertise in analog mixed-signal integrated circuit design; sales: ~85% automotive
- Main strength: **Deeply understand our customers application needs** to create system innovation

ENABLING GROWTH
- **Global player for automotive** ASSPs and ASICs
- Specialized **design and application experts**; worldwide sales offices and application support
- **Fablet approach**: Flexible production strategy for wafer processing and test operations

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Setting Standards in Innovations

BUSINESS LINE 1

RANGING

SENSOR INTERFACES

OPTICAL

BUSINESS LINE 2+3

MOTOR CONTROL

LIGHTING

SAFETY, POWER & CUSTOM ICs

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Product Segment - Optical

TRANSFORMING USER EXPERIENCE

- Intuitive and robust: Pioneering in automotive gesture control with >50 million ICs in the field
  - Proximity and swipes
  - Object detection
  - Touchless door / trunk access
- Reliable and eco-friendly
  - Presence and motion detection
  - Rain and light sensing
  - Smoke detection
- Development of LiDAR key components
  - Highly efficient optical CMOS receivers
  - LiDAR read-out ICs
  - Best of class laser diode driver

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Agenda

- 3D ToF Imager Automotive Applications
  - Interior Applications
  - Exterior Applications

- ToF Measurement Principle
  - Direct and indirect ToF

- Calibration of a 3D ToF Imager
  - From raw data to a real distance value
ToF Applications - Overview

Applications for automotive sector

- Interior applications
  - Driver Monitoring
  - People detection
  - HMI/Infotainment

- Exterior applications
  - Automatic Doors
  - Easy Open Liftgate
ToF Applications – Close up

**Easy Open Liftgate**
State of the art technology: Capacitive sensors

*ToF Imager for Easy Open Liftgate:*
- Guided Gesture (with personalized light emblem)
- Easy installation
- Robust against humidity, malfunctions

**HMI**
State of the art technology: HR cameras

*ToF Imager for HMI:*
- Good cost/performance ratio (adequate resolution for finger recognition)
- Robust in all lighting conditions
- Low power consumption
ToF Measurement Principle

Direct Time-of-Flight

- Run time measurement
- Speed of light makes direct measurement difficult
- Very precise TDCs necessary
- Difficult for high number of pixels

Indirect Time-of-Flight

- Measurement of charge carriers in expected time range
- Continuous wave (cw) or pulsed modulated (pm) method
Indirect ToF Measurement

- Indirect Time-of-Flight

- Distance calculation from the ratio of partial charges
  - Q1: starts with light pulse
  - Q2: starts with end of light pulse
  - Q3: charge due to background light
  - $T_{\text{trig}} =$ light pulse duration

- Sequence is repeated N-times before readout happens

\[ d = \frac{c}{2} T_{\text{trig}} \frac{Q_{2,\text{eff}}}{Q_{1,\text{eff}} + Q_{2,\text{eff}}} \]
ToF Module

- ToF Sensor
- Lightsource
- Lenses
- µController

Multidisciplinary team working is necessary to build a ToF Module!
Standard photodiode structure

- Potential in the n well is pinned through the two pn junctions at the top and bottom
- No electric field in the well

Unique lateral drift field photodiode structure

- Dopant gradient in the n-well to generate an e-field
- Additional Collection Gate (CG)
- Electrical field inside the diode

std-stand.png

Elmos PD
Elmos ToF Sensor – 527.31

- 46 x 46 pixel (32 x 32 pixel used)
- Pixel size: 40 x 40 \(\mu\)m
- Suitable for LEDs and laser light sources (850 - 940 nm)
- Low power always-on-stand-by architecture
- Sleep Current: 14 \(\mu\)A
- Full Operation Mode Current: 2.6 mA
- On board temperature sensor
- Integrated light source control with programmable modulation frequencies
- Programmable Q shutter times
Raw values show high deviations
Measured distance deviates from target distance curve
Calibration of pixel individual gain and offset necessary!
Imager Characterization – Offset

- Small gradient in x and y direction
- Statistical pixel-to-pixel variation of the dark-value in the range of +/-20 LSB
- Influence of the offset must be eliminated by suitable distance calibration
Pixel-to-pixel variation under illumination (homogenous, constant (not pulsed) LED-light source, center wavelength=850nm, shutter setting time 31.25ns)

- Photo response non-uniformity

Influence of pixel-to-pixel variation must be eliminated by suitable distance calibration

With illumination
Calibration with 2 coefficients
- Measurement of 6 distances
- Background subtraction
- Mean value of each pixel on each distance
- Build linear equations for measured distance from raw values for one pixel with 1 and 2 coefficients
- Solve linear equation system

- Gain and offset calibration lead to more precise distance values
ToF Gesture and Poses Detection

- Finger gesture detection with Elmos ToF Imager
- Distance values are color coded
- Only a small selection of possible gestures is shown (Victory, Forefinger, Palm)

- Intuitive gestures can be used to make the operation of the infotainment system easier and safer while driving
This work is funded by the German BMWi (Bundesministerium für Wirtschaft und Energie) in the frame of the Important Project of Common European Interest (IPCEI).

The IPCEI is also funded by Public Authorities from France, Italy and U.K.