Sensors for Building Automation

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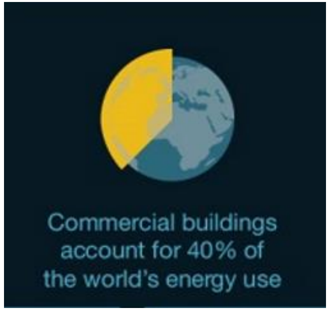
Engineering a Smarter Buildings

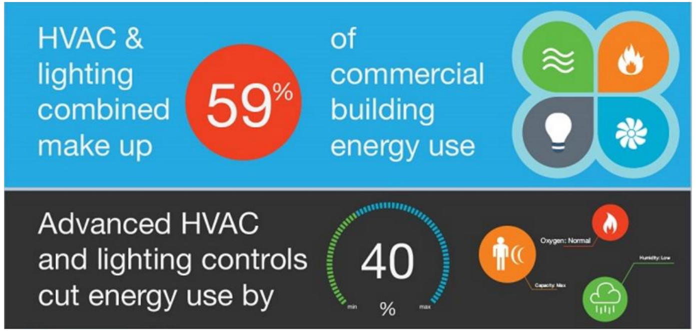
Industry Trends:

- Energy Efficiency
- Increasing Comfort
- Increasing Safety & Security
- Data
  - Connected & Cloud Driven
  - Higher accuracy
  - More frequency
  - Greater Localization

Energy Efficient Buildings

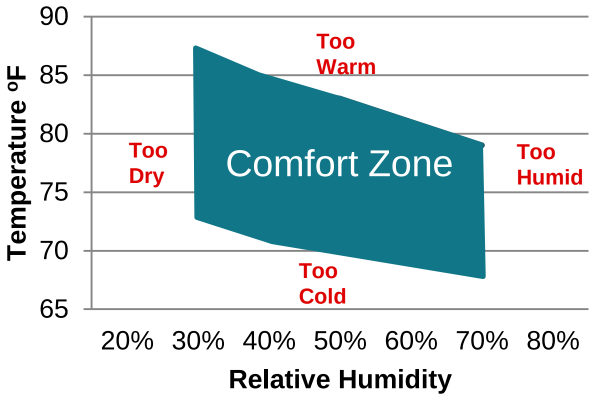


- Energy Savings thru Greater Intelligence:
  - People Counting
  - Distributed Sensor Networks
  - Big Data Analysis



Optimizing the thermostat

- Fast & Accurate Temperature Measurement
  - Reduce overshooting target temperature
  - Consumer Benefit: Greater Comfort, Energy savings
- Optimizing for comfort not just temperature (Psychrometric Factors)
  - Temperature
  - Humidity
  - Airflow
  - IR Radiation



Achieving Accuracy In a thermostat

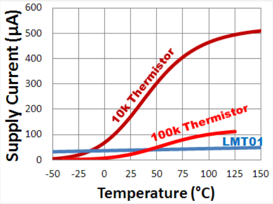
Reduce Self Heating

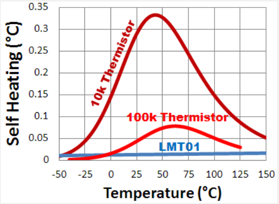
Accuracy problem: For low noise and minimized effects of parasitic resistances, a low value thermistor (10kΩ or less) should be chosen

Accuracy trade-off: Low value thermistor introduces more error from self-heating

Power trade-off: Low value thermistor draws more current and increases average power dissipation

Solution: Use IC-based sensor for minimal self-heating, low average power consumption across temp range, and consistently high accuracy





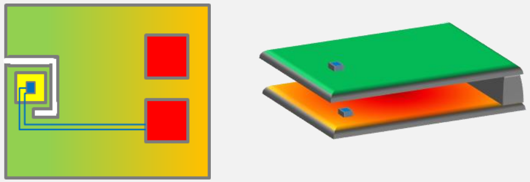
Thermal Design Considerations

Isolate: Thermally decouple sensor from high power circuitry on the PCB while increasing thermal transfer with the air.

Differential Measurements: Calculate the ambient temp by thermally modeling the temperature delta between two sensors.

Reduce Thermal Mass: Smaller sensors & less PCB around the sensor for faster thermal response

Passive Air Flow: Design housing to leverage self heating to draw fresh air past sensor



Recommended Devices

TMP112:
- +/0.5C accurate
- 10uA (max), 1.4V Capable
- Compact SOT-563 package (1.6 x 1.6 x 0.55mm)
- I2C Interface

TMP108:
- +/0.5C accurate
- 6uA (max) 1.4V Capable
- Ultrasmall WCSP package (1.2 x 0.8 x 0.625mm)
- I2C Interface

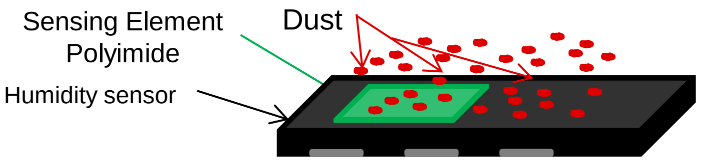
LMT70:
- +/0.13C accurate
- 12uA (max) 2.0V Capable
- Ultrasmall WCSP package (0.88 x 0.88 x 0.6mm)
- Analog Out

LMT01:
- +/0.5C accurate
- Pulse Counter Interface
- 2 Pin package

LMT84:
- Fast TO-92S package
- Analog Out

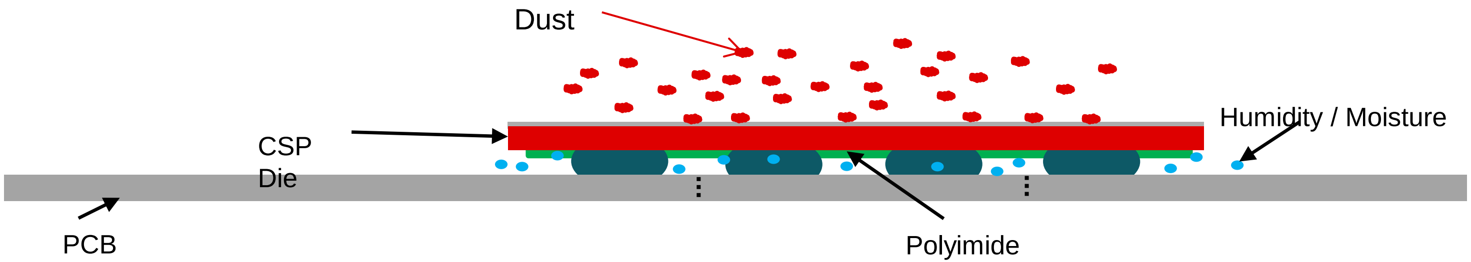
Protecting the humidity sensor

Classical solution in DFN package



- Dust falls on top of the sensing element reducing the performances until the complete blockage of the sensor
- Some competitors suggest to cover the sensor with a filter/grid (very expensive more than the device itself)

HDC1010 intrinsic dust resistant structure



- HDC1010 has the sensing element on the bottom part of the sensor.
- Sensing element is intrinsically protect from the dust that falls on the top part

HDC1010

Humidity & Temperature Sensor

Features

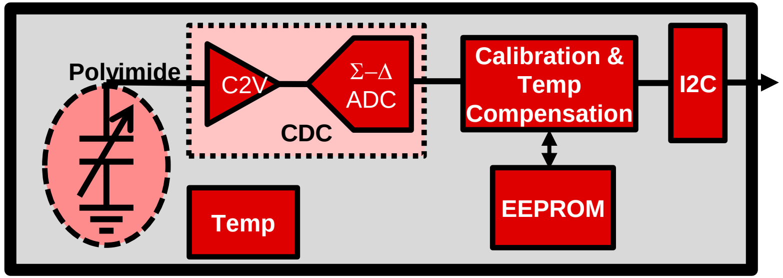
▪ Relative Humidity Range	0% to 100%
▪ Humidity Accuracy	±2%
▪ Typical Drift	< 0.5%/yr
▪ Supply Current (Measuring)	180uA
▪ Avg Supply Current (@1sps)	1.3uA
▪ Temperature Accuracy	±0.2ºC
▪ Temperature Range (Operating)	-20ºC to +85ºC
▪ Operating Voltage	2.7V to 5.5V
▪ Package	
▪ 8 pin WLCSP HDC1000 (1.59mm x 2.04mm)	

Applications

- HVAC
- White goods (dryer, fridge, microwave, dishwasher)
- Printers
- Handheld Meters
- Camera Defog
- Smart Thermostats and Room Monitors
- Medical Devices

Benefits

- Completely integrated humidity and temperature IC provides guaranteed performance
- Fully calibrated sensor enables quick time-to-market
- Very low power consumption
- Small package size supports compact designs



Localized sensors & control

Low power wireless sensors to provide localized environmental monitoring to control thermostat and/or zone controlled ventilation.

Humidity & Temperature Sensing Node for Sub-1 GHz Star Networks Enabling 10+ Year Coin Cell Battery Life

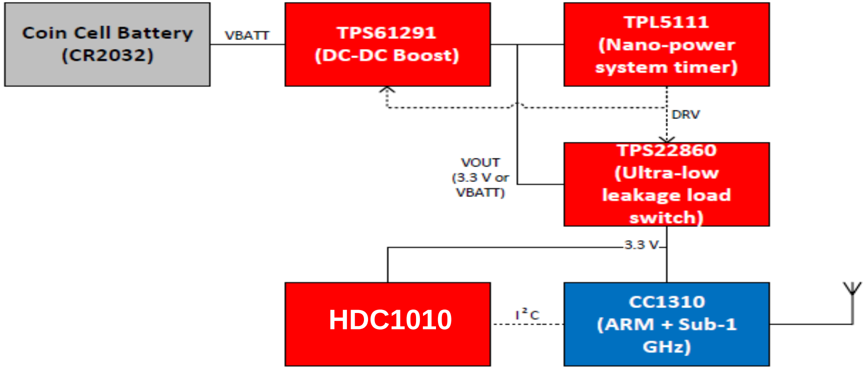
TI Designs Number: TIDA-00484

Solution Features

- Configurable System Wakeup Interval
- Extremely low off-state current (270 nA for 59.97 seconds)
- Ultra low on-state current due to low active processor and radio transmit currents (3.376 mA for 30 ms)
- Extended transmit range due to Sub-1 GHz radio
- ±3% Relative Humidity Accuracy
- ±0.2°C Temperature Accuracy

Solution Benefits

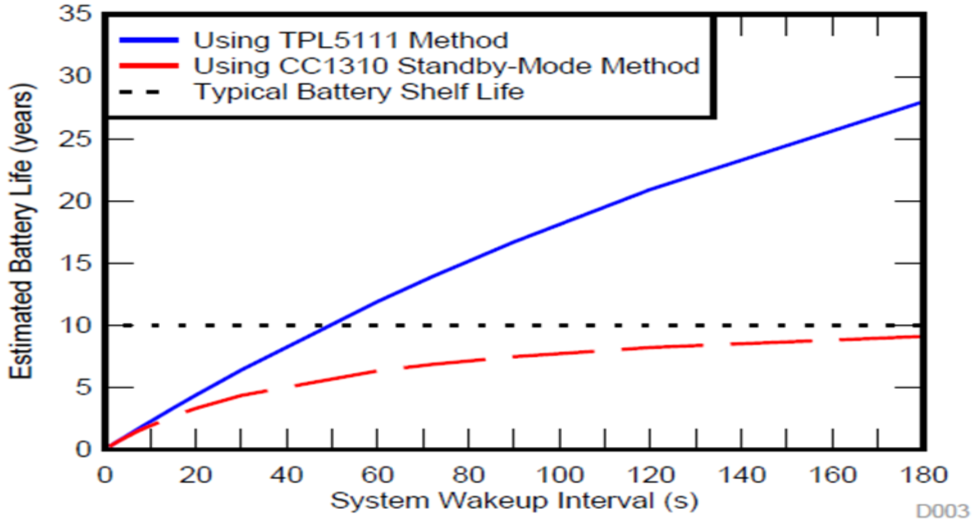
- Use of Nano-Power System Timer to Duty-Cycle the System Results in 10+ year battery life from CR2032 coin cell
- Small, integrated solution size due to the integrated sensor and radio SoC



Tools & Resources

- **TIDA-00484 Tools Folder**
- **User Guide**
- **Design Files:** Schematics, BOM, Gerbers, Software, and more
- **Device Datasheets:**
  - HDC1000
  - TPL5111
  - TPS22860
  - TPS61291
  - CC1310

TPL5110 test results: comparison of the topologies



Estimated Battery Life Comparison: TPL5111 Nano-Power System Timer Versus CC1310 Standby Mode

Humidity & Temperature Sensing Node for Star Networks Enabling 10+ year Coin Cell Battery Life

TI Designs Number: TIDA-00374

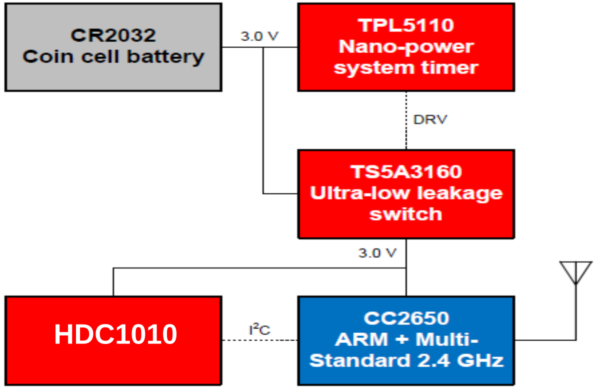
TIDesigns

Solution Features

- HDC1010 humidity and temp digital sensing
- Detect relative humidity from 0 – 100%
  - ±3% accuracy
- Detect temp. at ±0.2°C (nominal) over 5°C to 60°C
- Configurable sleep time
- Power management partitioning for extremely low power consumption

Solution Benefits

- Small, integrated solution size due to the integrated sensor and radio + mcu SoC
- Long Battery Lifetime: Designing for 10+ years off a single CR2032 coin cell battery



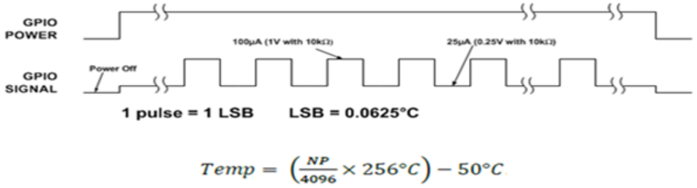
Tools & Resources

- **TIDA-00374 Tools folder**
- **User Guide**
- **Design Files:** Schematics, BOM, Gerbers, Software, and more
- **Device Datasheets**:
  - HDC1010
  - TPL5110
  - TS5A3160
  - CC2650

Digital Replacements for HVAC Temperature Probes

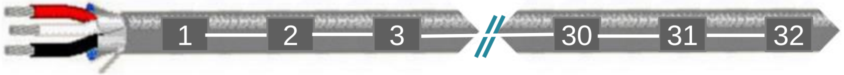
LMT01: Pulse Count Temp Sensor

- Simple 2 Pin Interface
- Mechanically compatible with existing hardware
- 0.5oC Accuracy



TMP107: Daisy Chan Temp Sensor

- String multiple temp sensors in a single cable up to 300m
  - Reducing wiring & assembly costs
- ½ Duplex UART Interface
- 0.4oC Accuracy



Fire Safety

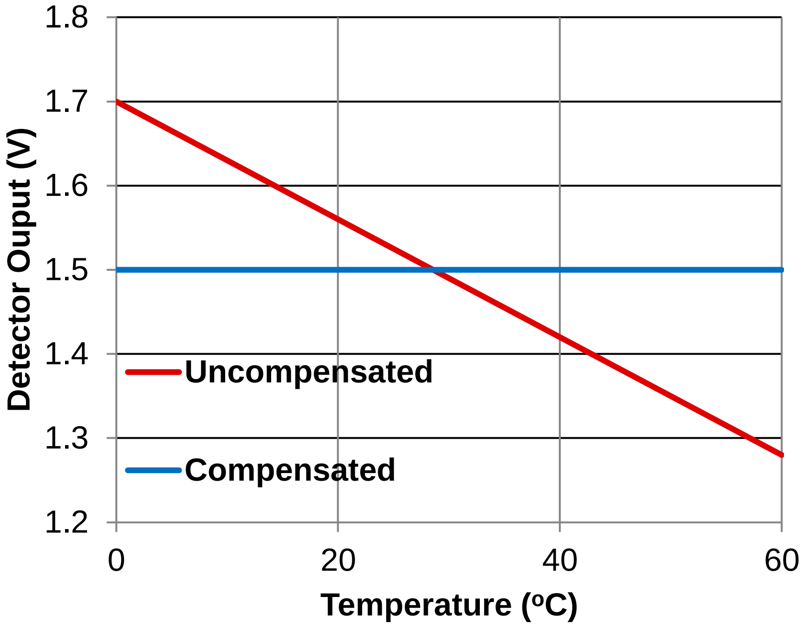
Smoke Detectors

- A device that detects an abnormal concentration of smoke, typically an early indication of a fire.
- Two basic types: Ionization and photoelectric
- Industry Standards
  - UL-217 North American
  - EN-54-7 European
- Commonly detect CO also
- Temperature sensor used for circuit compensation

Heat Detectors

- Detects abnormally high temperatures or fast temperature increases
- Fixed-temperature or Rate-of-Rise
- Industry Standards
  - UL-521, UL-539 North American
  - EN-54-5 European
- Common Trip Points
  - 135^{o}F for Fixed Temp
  - +15^{o}F/minute RoR
- Temperature sensor used to monitoring the environment

Temperature Compensation for Photoelectric Smoke Detection



Graph shows hypothetical representation of smoke detector output vs temperature.

- Temperature has a significant impact on photoelectric smoke detector output level. **Failure to compensate for temperature can cause false alarms**.
- Temperature-dependent characteristics of IR LED
  a) Spectral distribution
  b) Light emission intensity
  c) Forward voltage
- **Temperature sensors can be used to mitigate these errors**

UL-521 Specification for Heat Detectors (1999 Ed)

System-Level Spec

UL-521 Oven Test for 15-ft Spacing

- Ordinary Class temperature range: 29.4C-78.9C
- Response time t ≤ 2 min
- Approximate oven rate-of-rise $\alpha \approx$ 33.3 C/min

Applying Thermal Model (EN-54-5)

$$\Delta T = \alpha(t - \tau_u(1 - e^{-\frac{t}{\tau_u}}))$$

- $\Delta T \sim$ temperature rise [C], ΔT = 40 C for A1
- $\alpha \sim$ rate of rise [C/min]
- t ~ response time [sec]
- τ_u~ thermal time constant [sec] @ airflow of u [m/s]

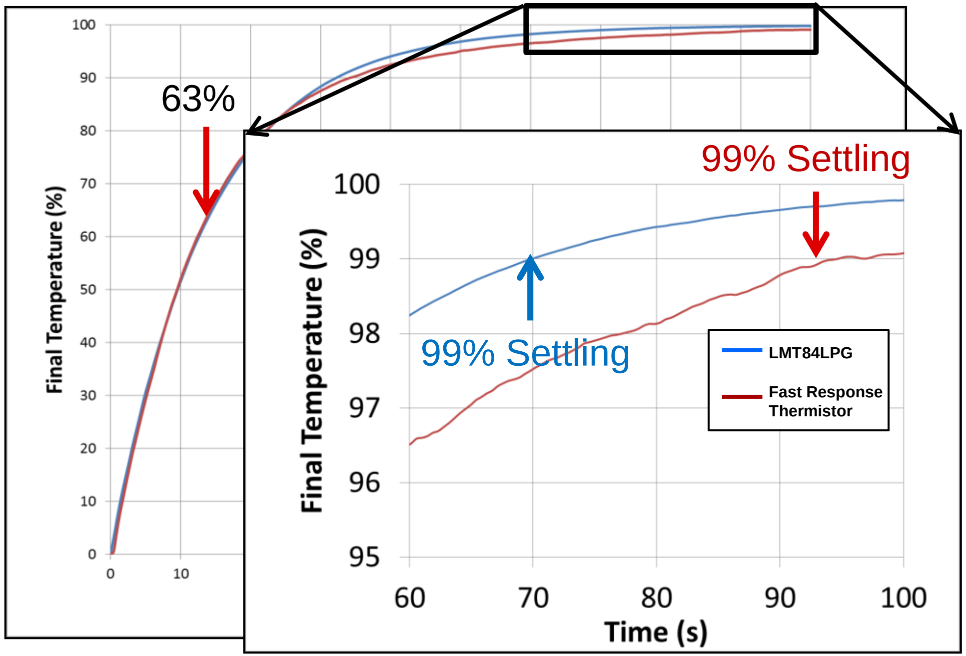
Component-Level Spec

The system-level specifications define the component-level requirements. In this case, a time constant of

$\tau_u \leq$ 30 sec

is needed to meet the system-level specifications of UL-521 Oven Test

LMT8xLPG vs Fast Thermal Response Thermistor



Test Conditions:

- T_i=25ºC, T_f=70ºC, Airflow=1.2m/s
- Directional dependency ~ 2 sec

Time Constant	Fast Response Thermistor	LMT84LPG
63% (t)	13 sec	13.5 sec
99% (5t)	94 sec	70 sec

LMT8xLPG supports UL-521 ($\tau \leq$ 30 sec)

- Comparable thermal response
- Faster settling time

Additional Benefits of LMT8xLPG

- Guaranteed accuracy across wide temp range
  - No calibration required
  - Linear output
- Low power: 9uA (max)
- Fast Startup: 1.9ms (C_L= 0 pF to 1100 pF)
- Family of gain & supply options

TI Part	Accuracy °C (max)	Gain mV/°C	Supply
LMT84	±2.7	-5.5	1.5 V to 5.5 V
LMT85	±2.7	-8.2	1.8 V to 5.5 V
LMT86	±2.7	-10.9	2.2 V to 5.5 V
LMT87	±2.7	-13.6	2.7 V to 5.5 V

Optical Solutions in BA - Daylight Harvesting & Occupancy Detection

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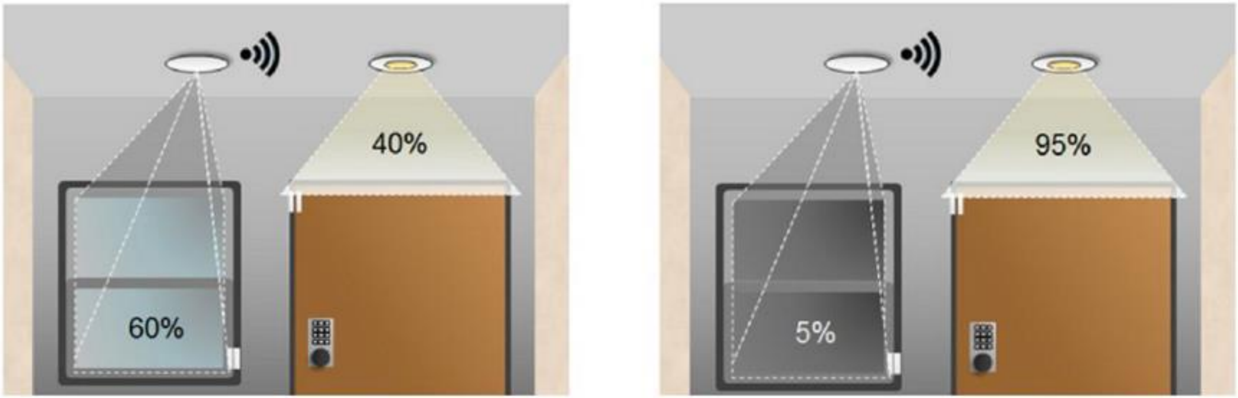
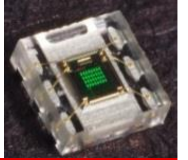
Daylight Harvesting

- Smart control of the building lighting by monitoring ambient light and adjusting artificial lighting accordingly
- Each energy code has specific rules on daylight zones
- Trade-off exists between battery life and frequency of data collection for sensor nodes
- Secondary Benefit: Compensation for aging effects of the bulbs "Luminary Maintenance"



OPT3001- Ambient Light Sensor

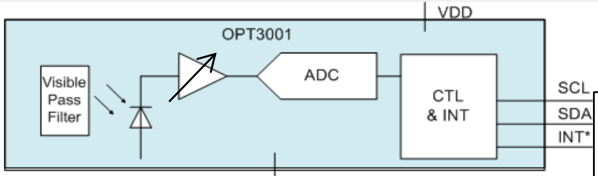


Features

- Good Human Eye spectral matching
  - <1% IR Response
- Optical Power Sensitivity
  - 0.01 – 83,000Lux
  - Automatic range setting
- Tight Absolute Accuracy: 10%
- Wide 1.6V - 3.6V Power Supply Range
- Low 1.8uA (typ) Operating Current.
- Flexible Interrupt System
- Small 2.0 x 2.0mm Package

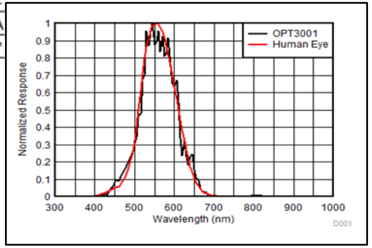
Benefits

- Best Representation of Human Experience
  - Low measurement variation between light sources Florescent, Sunlight, Halogen, etc.
  - Especially good under dark glass
- Tight accuracy can eliminate need for calibration
- Interrupt system allows system to go to sleep until a relevant optical event
- Simpler Software, no req. for proper range selection
- Low operating current allows long operating life on small batteries



Applications

- Lighting, Building/Home Automation
- Any Lit Screen Exposed to Varied Lighting
- Any Lighting Control Changing with Ambient
- HMI: Displays Intensity Control
- Automotive and Consumer



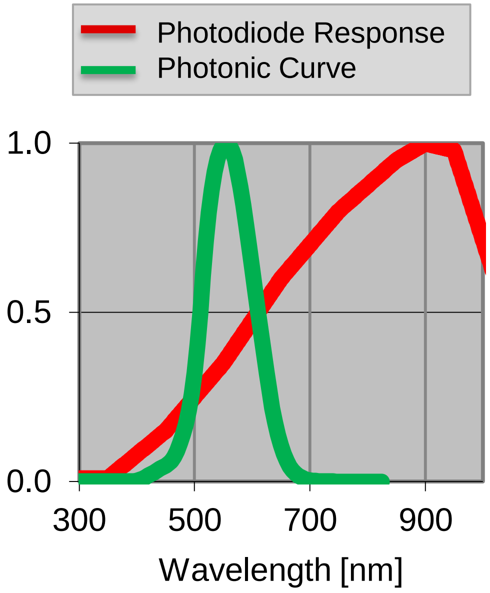
Human Eye vs OPT3001

TEXAS INSTRUMENTS

Why Not a Photodiode?

- Spectral sensitivity does not match human eye

- Strong IR sensitivity can result in larger errors on IR intensive light sources (sun, incandescent, halogen)

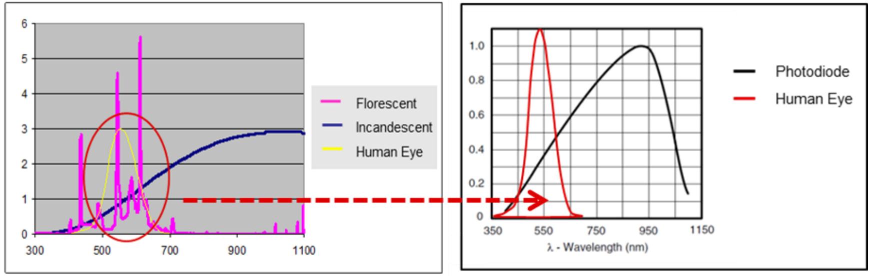


- Trans-impedance amplifier can be challenging to design

- Difficult to measure low light levels due to leakage currents (dark currents)

OPT3001 Benefits

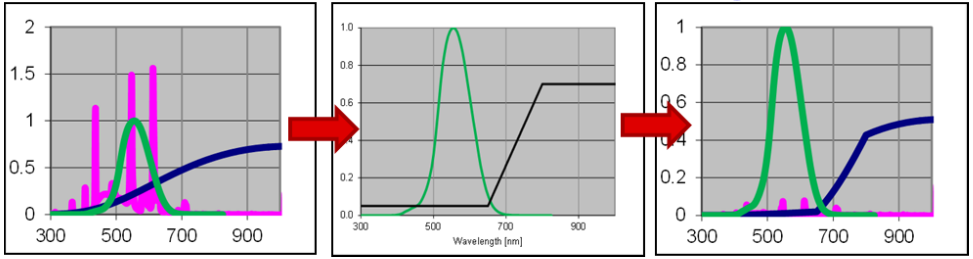
- Human Eye Response
- Improved user experience
- Accurate measurement of ambient light



Light Spectrum of Real World

Human Eye vs Photodiode

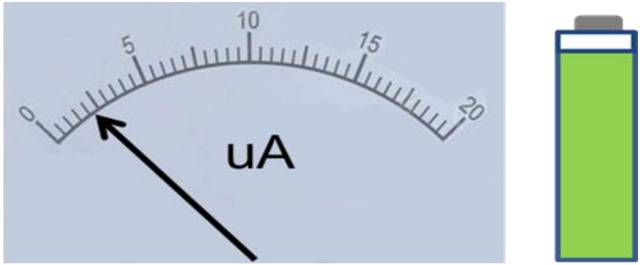
Input Spectrum X Glass Spectrum → Light to Device



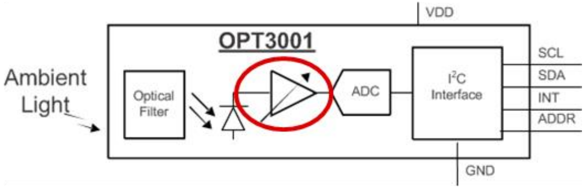
- Dark Glass transmits IR
- Sources like Incandescent has high IR
- OPT3001's excellent IR rejection helps prevent erroneous reading of light level

OPT3001 Benefits

- Ultra-low power → extends battery life and enables frequent light measurement



OPT3001 is ~2uA Operational current

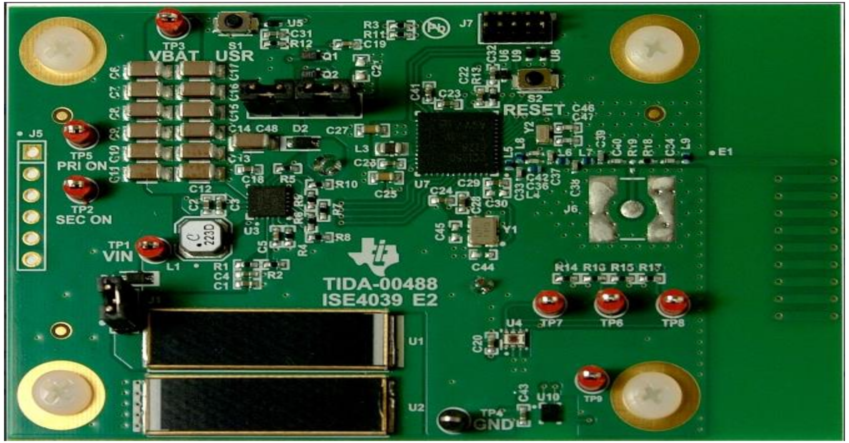


- Auto-gain setting feature helps adjusts internal setting automatically based on input light level
- No additional adjustment required
- Always in optimal range with good resolution and tight accuracy

TIDA 00488: Energy Harvesting Ambient Light and Environment Sensor Node for Sub-1GHz Networks Reference Design

Description:

Uses ultra-low power and a renewable method of wireless environmental sensing using daylight energy harvesting. Senses natural ambient light coming into the building to precisely control the building's lighting systems.



Features:

- Long backup battery life (up to 10 years) in interrupt mode
- Senses natural ambient light coming into a building to precisely control the building's lighting systems
- Monitors temperature and relative humidity in addition to ambient light

Applications:

- Energy Harvesting
- Environmental sensor

Resources:

- http://www.ti.com/tool/TIDA-00488

3D Time of Flight Solutions (ToF) for Occupancy Detection

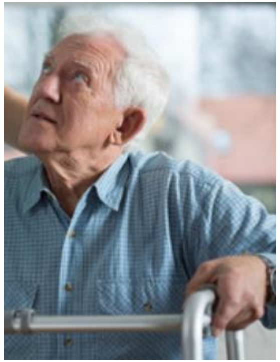
Occupancy Detection – Use Cases

Surveillance

Note:

$45B lost due to theft and fraud in US stores [1]

Home Monitoring for Elderly & Patients



Note:

1.8M elderly Americans treated for fall injury in 2004[2]

Demand Controlled Ventilation

Note:

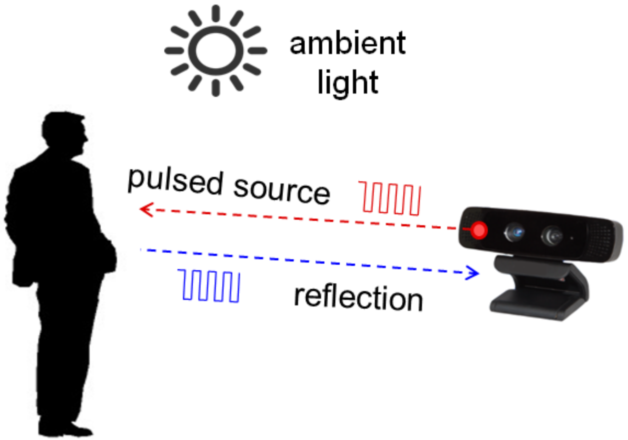
In 2013, US building energy cost topped $321Billion

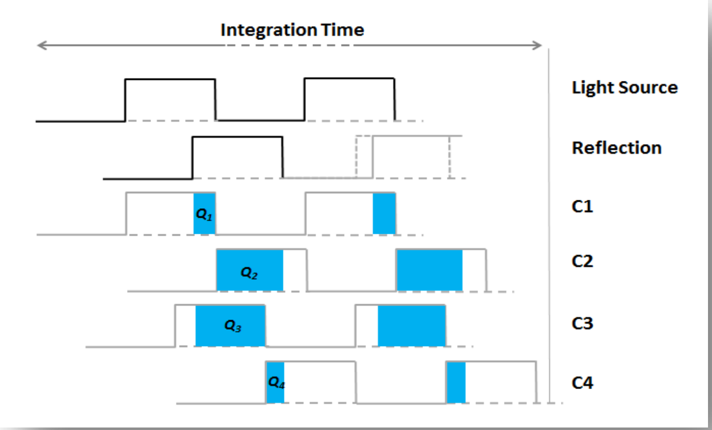
Queue/Checkout Line Monitoring

Note:

Excessively long line may lead to a loss of business

Theory of operation

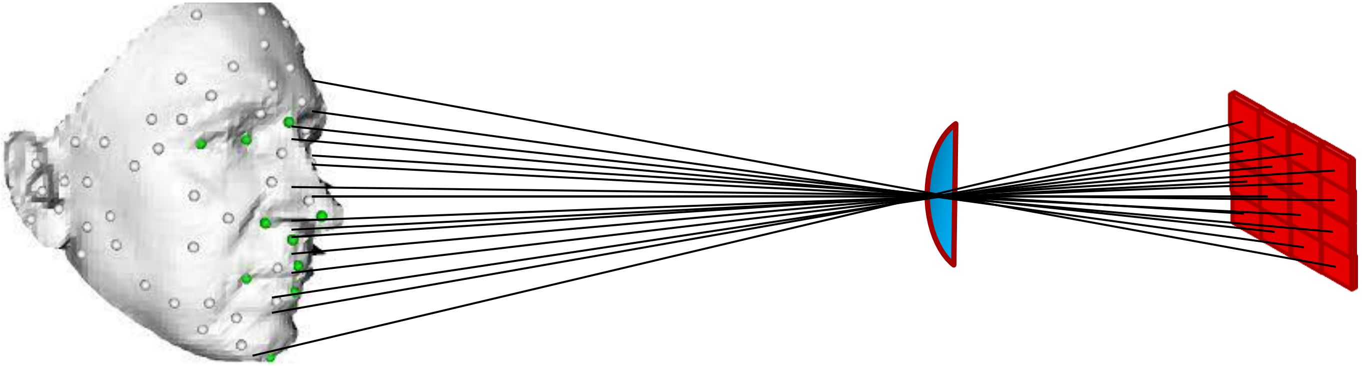




$$\phi = \arctan\left(\frac{Q_3 - Q_4}{Q_1 - Q_2}\right) \qquad d = \frac{c}{2f} \cdot \frac{\phi}{2\pi}$$

Distance measured by emitting a modulated light and measuring phase delay of returned light

How 3D Time of Flight Sensor Works



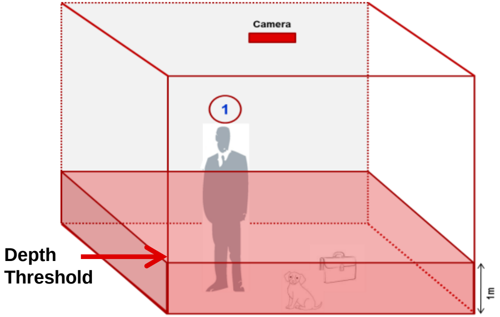
Single pixel measures distance to a single point

An array of pixels are used to map a region

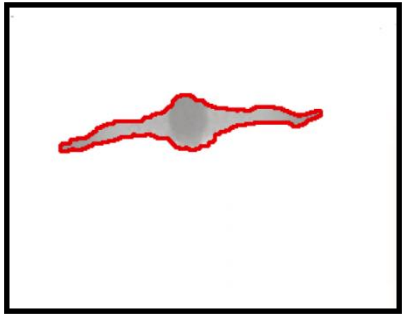
ToF Camera Output

Figure-Ground Separation (Top View)

Sampled Image



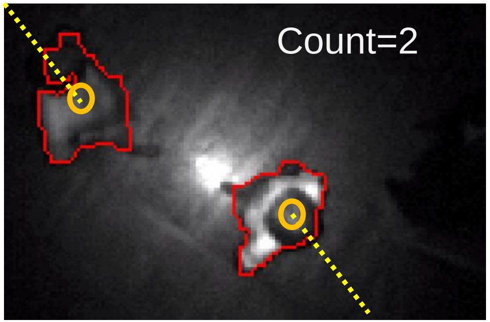
Thresholding

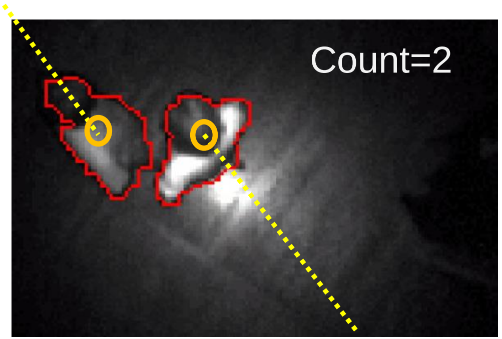


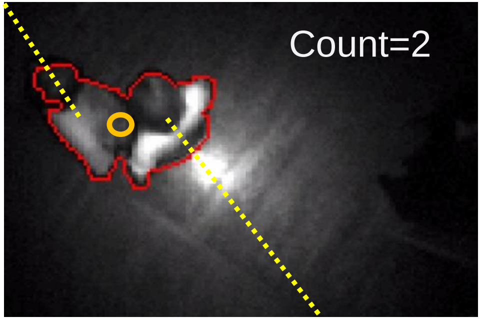
Foreground

- **Find the “bodies” in the image using depth as threshold**
- **One can generally assume the pixel closest to the camera is the head**
- **If necessary, crop out any surrounding pixels violating this assumption**

Keypoints Tracking



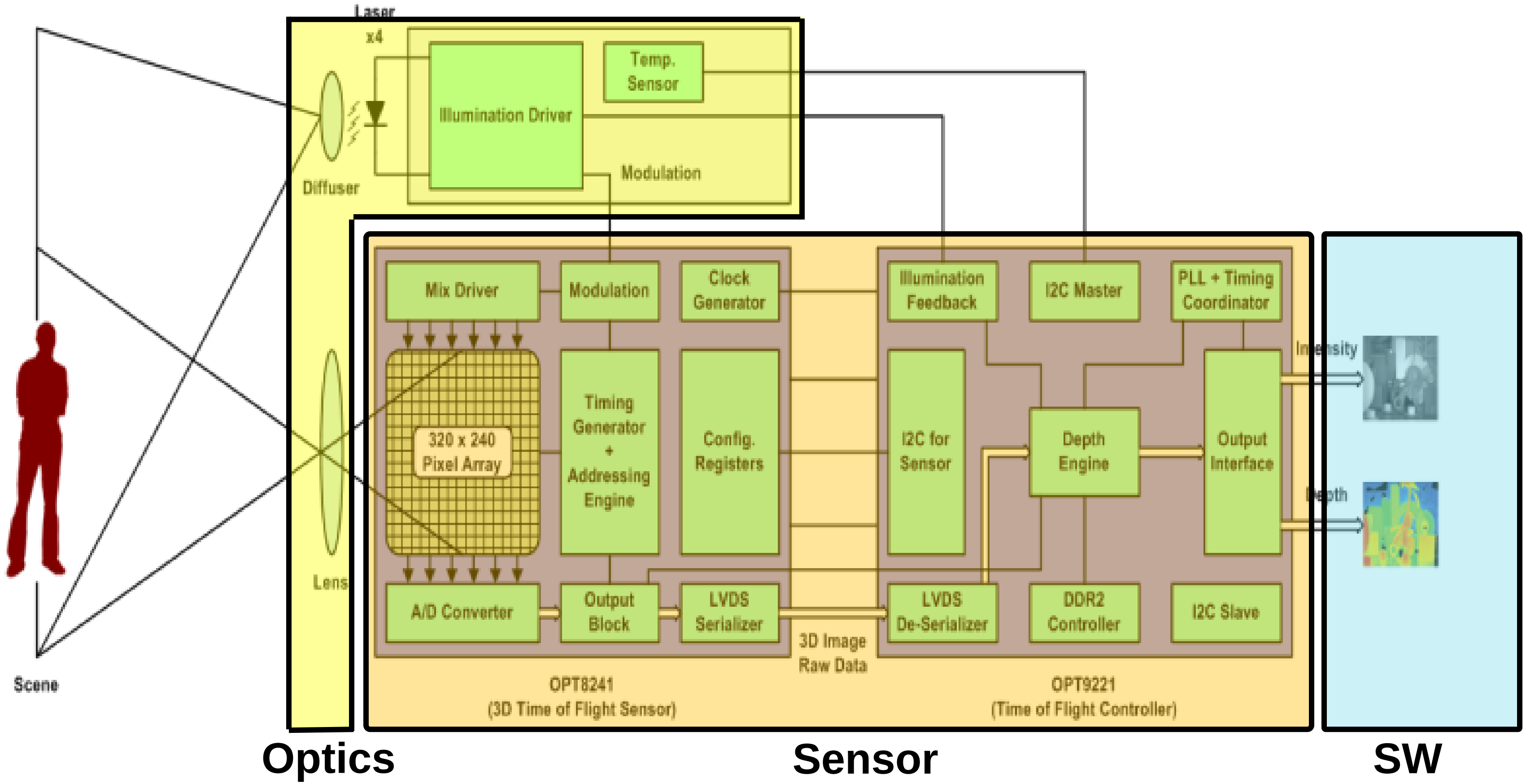




- **Trajectory is a history of keypoint position**
- **For each frame, each keypoint is matched to the nearest trajectory**
- **Number of active trajectories indicates number of persons**
- **Mismatching #keypoints and #trajectories reconciled based on known constraints**

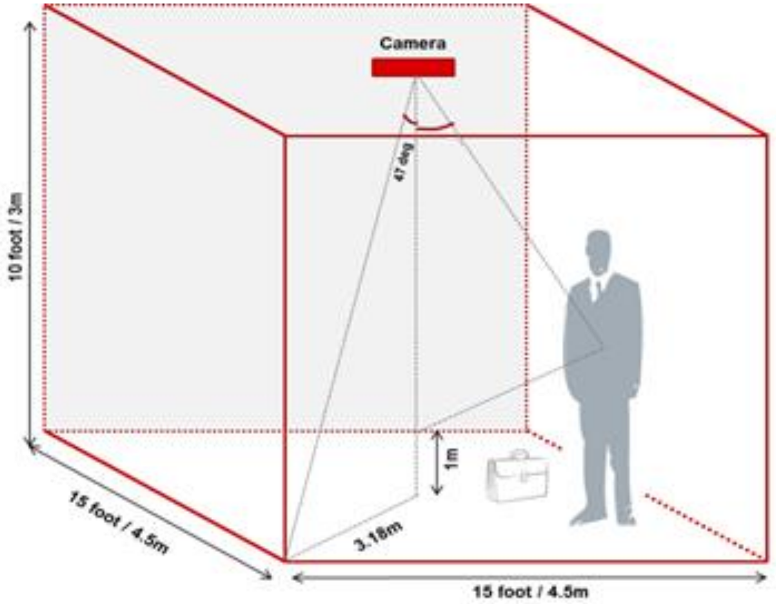
Video showing side view person

Typical System Diagram

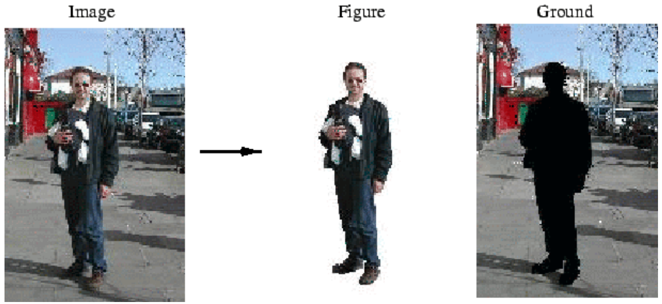


Choosing the Right Resolution

- The smallest object that can be seen from the camera theoretically is dictated by:
  - Field of View (FOV)
  - Pixel Resolution
- Presence of noise requires smallest object to be greater than a pixel



Algorithms



Foreground-Background Separation

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Convert to binary Image and Apply Morphology Filters

↓

Shape Analysis

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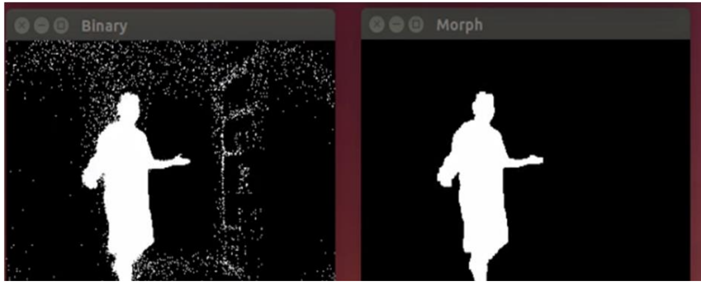
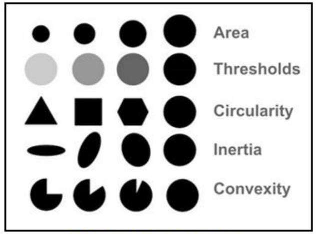
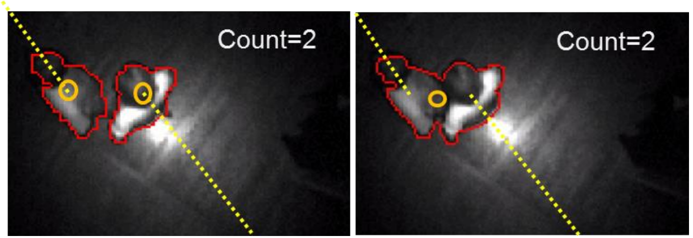
Tracking





Blob Analysis

Contour Analysis



TI Design (TIDA-00750): People Counter for HVAC

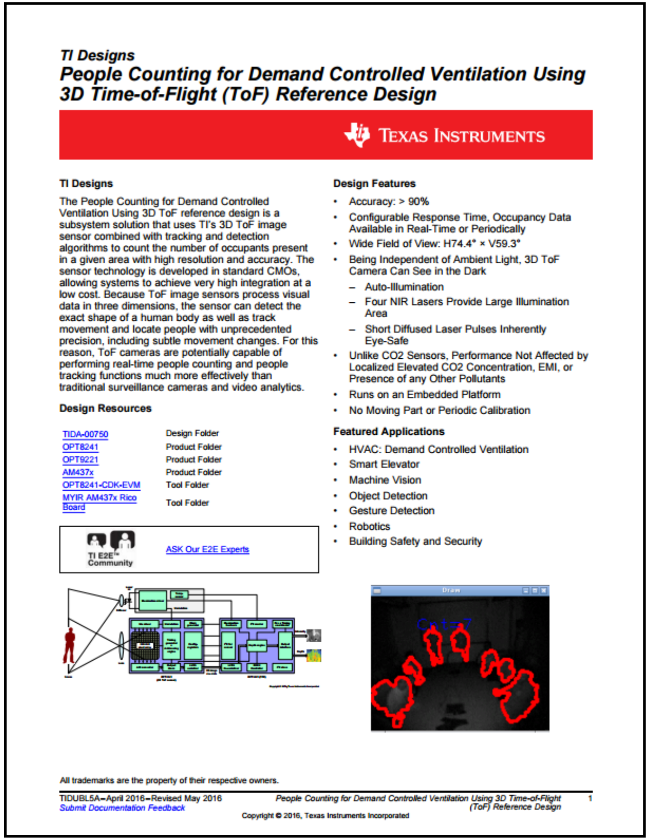
Description:

This is a 3D Time of Flight based occupancy detection reference design that is used for people counting.

Features:

- Configurable response time, occupancy data available in real-time or periodically
- Wide field of View: H74.4º x V59.3º
- Being independent of ambient light, 3D ToF camera can even see in the dark
    - Auto-illumination
    - Four NIR lasers provide large illumination area
    - Short diffused laser pulses inherently eye-safe
- Runs on an embedded platform

http://www.ti.com/tool/TIDA-00750



TI Designs

People Counting for Demand Controlled Ventilation Using 3D Time-of-Flight (ToF) Reference Design

TEXAS INSTRUMENTS

TI Designs

The People Counting for Demand Controlled Ventilation Using 3D ToF reference design is a subsystem solution that uses TI's 3D ToF image sensor combined with tracking and detection algorithms to count the number of occupants present in a given area with high resolution and accuracy. The sensor technology is developed in standard CMOs, allowing systems to achieve very high integration at a low cost. Because ToF image sensors process visual data in three dimensions, the sensor can detect the exact shape of a human body as well as track movement and locate people with unprecedented precision, including subtle movement changes. For this reason, ToF cameras are potentially capable of performing real-time people counting and people tracking functions much more effectively than traditional surveillance cameras and video analytics.

Design Resources

TIDA-00750	Design Folder
OPT8241	Product Folder
OPT9221	Product Folder
AM437x	Product Folder
OPT8241-CDK-EVM	Tool Folder
MYIR AM437x Rico Board	Tool Folder

TI E2E™ Community — ASK Our E2E Experts

Design Features

- Accuracy: > 90%
- Configurable Response Time, Occupancy Data Available in Real-Time or Periodically
- Wide Field of View: H74.4° × V59.3°
- Being Independent of Ambient Light, 3D ToF Camera Can See in the Dark
    - Auto-Illumination
    - Four NIR Lasers Provide Large Illumination Area
    - Short Diffused Laser Pulses Inherently Eye-Safe
- Unlike CO2 Sensors, Performance Not Affected by Localized Elevated CO2 Concentration, EMI, or Presence of any Other Pollutants
- Runs on an Embedded Platform
- No Moving Part or Periodic Calibration

Featured Applications

- HVAC: Demand Controlled Ventilation
- Smart Elevator
- Machine Vision
- Object Detection
- Gesture Detection
- Robotics
- Building Safety and Security

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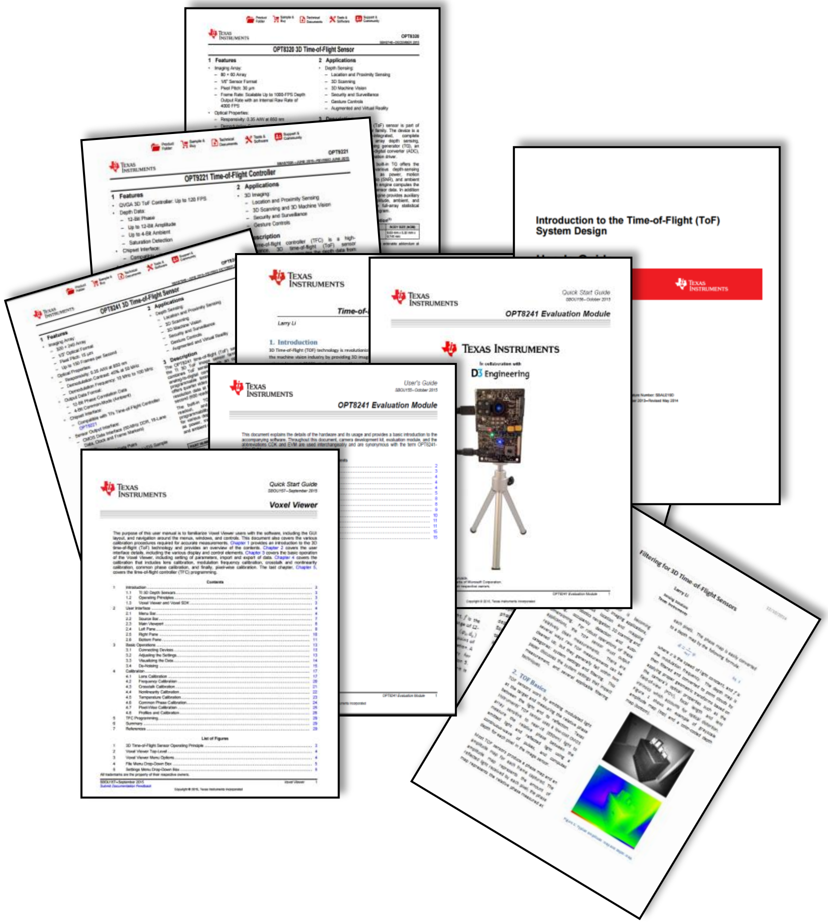
TIDUBL5A–April 2016–Revised May 2016 — *People Counting for Demand Controlled Ventilation Using 3D Time-of-Flight (ToF) Reference Design* — 1

Submit Documentation Feedback

Technical Documents

- Data Sheets
  - OPT8241
  - OPT9221
- White Papers
  - Time-of-Flight Camera—an Introduction
  - Time-of-Flight Camera Calibration
  - Filtering for 3D Time-of-Flight Sensors
- System Design Guide
- CDK Quick Start Guide
- CDK User Guide
- VoxelViewer User Guide
- “Getting Started with 3D Time-of-Flight Sensor” Video Series



http://www.ti.com/3dtof

Figure-Ground Separation (Side View)

Sampled Image

−

Background

=

Foreground

- **Finding “people” in a side view requires sampling of *background***
- **Subtracting background from sampled image will result in just the foreground, which contains object of interest**
- **Background can be updated by pixel-wise median filter**

Questions?

Thank you for attending

www.ti.com/sensors