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INTELLIGENT OPTO SENSOR

Number 37

DESIGNER'S

NOTEBOOK

TAOS TEXAS ADVANCED OPTOELECTRONIC SOLUTIONS®

Proximity Calibration and Test

by Kerry Glover

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Overview

TAOS proximity sensors are very flexible and are used in many applications from push button operation to cell phone touch screen disable to long distance human presence detection. In order to get the maximum performance from the devices, calibration may be needed to remove system-to-system variations. If calibration is performed, test may be a part of this procedure. If not, the system test would be implemented as a separate function.

The first several sections of this Designer's Notebook cover system calibration issues. The last sections will cover system test and test objectives.

Reasons for Calibration

There are many factors impacting the proximity measurement accuracy. The following figure outlines some of the factors causing system variation requiring calibration.

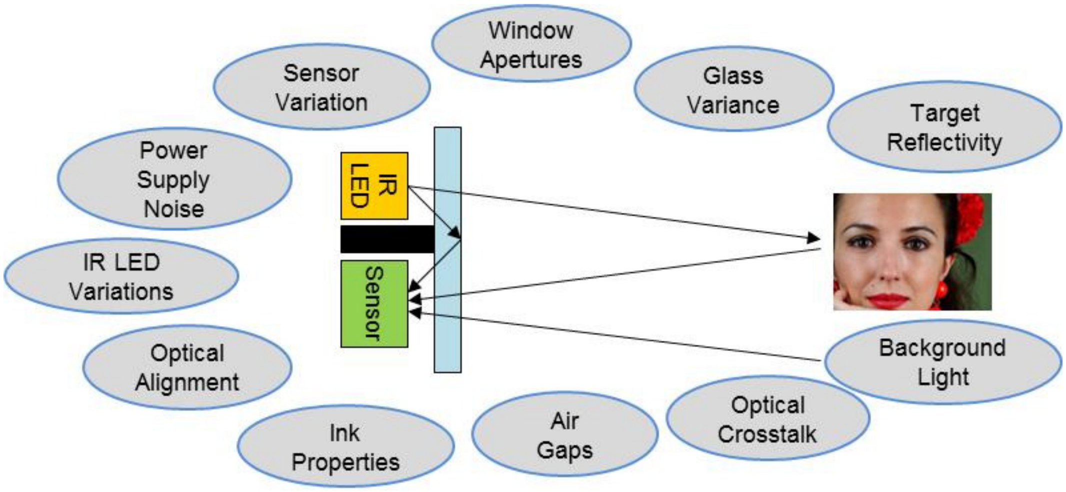

Figure 1 – Factors Impacting Proximity Detection

Standardized Target

In an optical system, each component in the optical path needs to be characterized to determine its extent, variation and statistical distribution. One of the first components in a test system that can be controlled is the surface reflectivity and size.

Gray cards made by photographic equipment manufacturers provide a repeatable/known reflective response. The Kodak Gray Cards have two sides, a gray side and a white side. The white side is 90% reflective while the gray side is 18% reflective. By using these cards, the specified reflectivity is ensured and standardized. In a test environment, these cards will need to be replaced periodically. The following shows both an Opteka and a Kodak gray card. The Opteka pack also contains a black card which can be used to emulate black human hair.

Figure 2 – Kodak and Opteka Gray/Grey Cards

The size of the card impacts the quality of the system calibration. As a general rule, it is recommended that the card be 2x wider than the distance to the target (d) to retain a repeatable 1/d^2 response. With an IR LEDs that has a small half-power emission angle (typically used in proximity sensor), the IR LED will not overfill the gray card maintaining the 1/d^2 relationship. For a 4” target distance, an 8x10 card is recommended. Also, it is important that the card be held stable and parallel to the sensor.

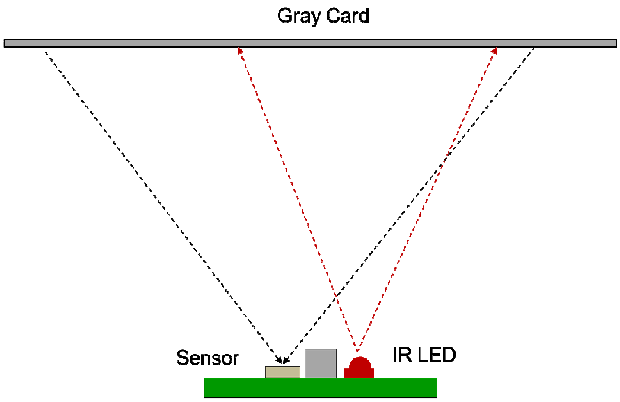

Figure 3a
Overfilled Card

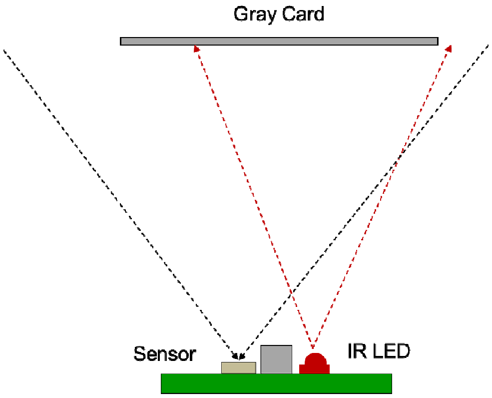

Figure 3b
Under-filled Card

If physical constraints don’t allow for an object that large, there are a couple of alternative. First, the gray card can be used instead of the white side which will reduce the distance by approximately 50%. Therefore, a 4” distance would be reduce to a 2” distance and a 4x5 card could be used. If a smaller card is used, consistency in card size and distance across all tests from subcontractor to final production would need to be ensured.

Gain and Offset Variations

Other factors can cause either gain or offset variations in the sensor response as shown in Figure 1. These variations significantly affect the sensor transfer function and will cause deviation in the proximity count at a fixed measurement distance.

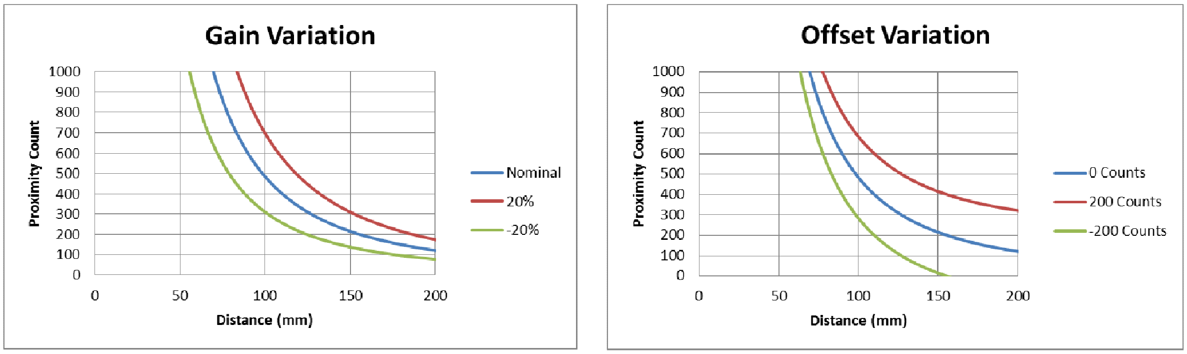

Figure 4 – Gain and Offset Variations

Observe from Figure 4 that the gain and offset variation look very similar at 100mm. For good calibration, both must be fully understood. In some cases, one or both of the factors can be characterized such that the impact is within the test limits. Calibration can also be used to correct for both variations as will be discussed latter in this document.

Gain variations include factors such as ink thickness, sensor trim accuracy, device alignment within the aperture, glass transmissivity and IR LED power variations. IR LED output intensity has the largest impact and can be trimmed out in a subassembly or module.

Optical crosstalk or electrical crosstalk can be cause offset variations. Optical crosstalk is impacted by the ink, airgap, enclosure/optical barrier design and glass thickness. Electrical crosstalk is impacted by system noise and intense stray light.

Variation Limits

Gain variation can be compensated by changing the proximity threshold count and/or the number of IR LED pulses. The number of pulses must first be set, then the detect count threshold can be determined. The gain variation is typically dominated by mechanical alignment and IR LED intensity which can vary by as much as 2x.

The offset will impact the dynamic range of the sensor. If the offset is positive, which is the case when crosstalk is an issue, the dynamic range will be reduced. If the offset is negative, which can be caused by electrical noise, calibration becomes more difficult.

Proximity Requirements

In order to determine a calibration procedure, the system requirements must first be examined. A first simple objective could be to detect an object at a fixed distance. For example, the detect distance could be 100mm using the white side of a Kodak Gray 8x10 test card (90% reflective).

This objective typically requires a “must detect” and “must release” threshold. If the thresholds are far enough apart, then calibration would not be required as they can accommodate the variability of most aspects of the system. Requirements have been seen as wide as 15mm to 200mm, or as narrow as 80mm to 120mm.

Another typical objective is to ensure that the system does not “chatter” at the detect point. This requires hysteresis to be built into the system. However, this hysteresis must be within the detect and release parameters mentioned above.

Target Size Impact

The following shows the significant difference in proximity readings as a function of the target size:

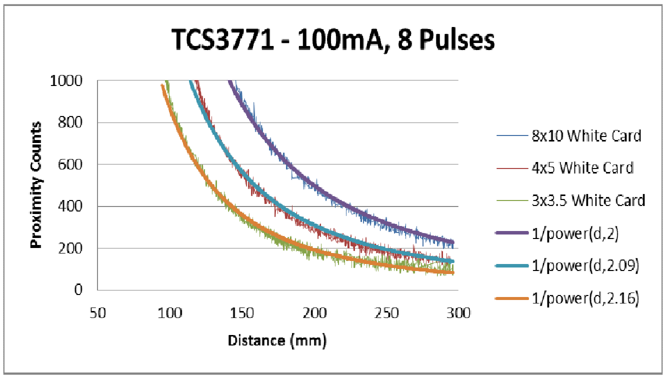

Figure 5 – Target Size Impact

With a smaller target, the proximity response is no longer $1/d^2$ but rather $1/d^{2.09}$ or $1/d^{\mathbf{2.18}}$ which changes with the test distance (d). For simplicity of calculations, keep the $1/d^2$ relationship and use a large card during the calibration portion of the testing. A smaller target can be used for testing if the response to the smaller target is properly characterized.

Figure 6 shows the results of a simulation showing a log-log plot of relative response versus distance. From this, it can be seen that the relationship changes from a $1/d^2$ relationship to a $1/d^4$ relationship as the distance is increased.

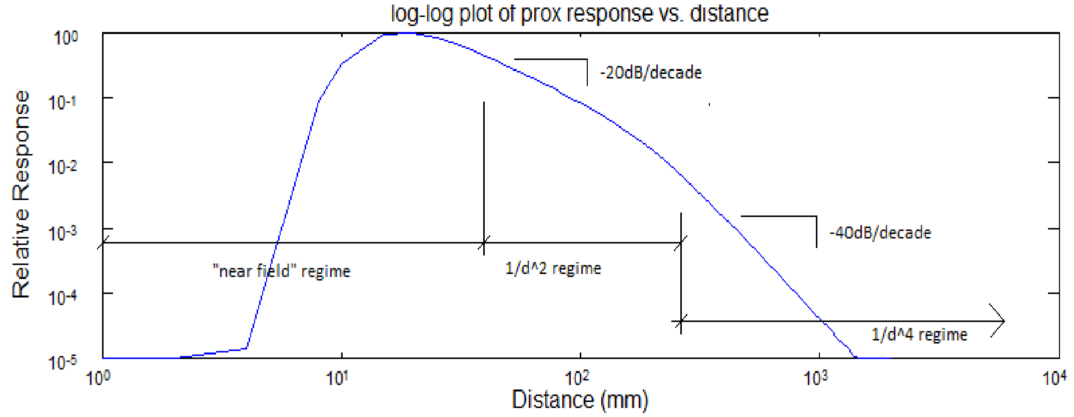

Figure 6 – Simulation Result - Relative Response vs Distance

System Characterization

Before a calibration methodology can be developed, the system should be fully characterized by measuring proximity count vs. distance. This requires a sampling of end system with component variation to understand the best and worst case scenarios. During the characterization process, the target size, number of IR LED pulses and proximity count should be established. For characterization, a number of end systems must be measured to determine the distribution. Best and worst case system components must be combined to determine upper and lower expected combinations.

The TAOS proximity devices allow programmable options for the number of IR LED pulses. In some products, offset is also programmable. The first step in the characterization is to determine the number of IR LED pulses. The next step is to determine the number of counts to set as a threshold.

The desired proximity count depends upon the application. For short or medium distance proximity detection, the desired proximity count is typically mid-scale. For long distance proximity, the desired proximity count is the lowest possible count just above the noise floor and the offset.

If the system variation cannot be compensated for by varying the desired proximity count, then the number of pulses may also be changed. However, the impact of changing pulse count is not linear. With a pulse count of 8, each pulse count change represents a 12% step change in proximity counts. As the number of steps decreases, this will get larger. For example, 5 pulses to 4 pulses is a 20% step change.

Dynamic Calibration

In some systems, the calibration routine may be implemented as part of the system algorithm. For example, if the goal is to detect the presence of a person in front of a monitor, the algorithm may want to be coupled with the computer to detect when keystrokes or mouse click have occurred an then the proximity detector would be turned on to determine the distance to the nearest target. Rather than detection a fixed target, the detector could determine if there is movement. To do this, the system would be dynamically calibrated to determine the current distance to an object and then the detection would be a change from that position. This would enable the device not to be fooled by a coffee cup on the table or the back of a chair facing the monitor.

Systems that Don't Require Calibration

If the system margin budget is broad enough or if the subsystem is calibrated, system calibration may not be required. If the system requirement is to guarantee detection of an object at 15mm but there is no release specification, the detection point should be set at a distance above 15mm giving plenty of margin to ensure detection at 15mm. For this example, assume the detect threshold is set to 60mm. The device variation of 20% creates about a 10% variation in this distance or a minimum of 54mm. The IR LED variation of 2x further reduces this by 70% or 38mm. Ink and glass variation can reduce this by another 20% to 30mm. A black vs. white detection surface can reduce this by 50% to the final 15mm detection distance. If more margin is needed, the 60mm detect distance would be increased.

If the sensor and IR LED are integrated in the same package, such as a module, the sensor and IR LED would be trimmed to a specific target power level. This can compensates for the 2x IR LED variation and the 20% sensor variation. In some cases, this will eliminate the need for calibration.

If the detection requirements are such that calibration is required, the first step is to determine what type of calibration is necessary. There are two types of calibration that will be discussed: Offset Calibration and Gain Calibration.

Offset Calibration Procedure - No-Target

If it is determined that the offset variation must be calibrated and the offset is positive or the device has programmable offset, then a simple calibration with no target can be implemented.

Recall from DN33 the formula for measuring distance: (see Table1 for acronyms)

PDATA/PPULSE ~ SR / (D * D) + CC + OFFSET

With a target at infinity, D becomes very large the formula reduces to:

PDATA/PPULSE ~ CC + OFFSET

Optical and electrical crosstalk can be combined into a single OFFSET value which is proportional to the PDATA and PPULSE. The final formula becomes:

OFFSET = PDATA/PPULSE

In some cases, the number of pulses is fixed and the OFFSET becomes a constant. In other cases, the algorithm requires the pulse count to change in which case the OFFSET must be calculated.

The final calibration process is simple in that with no target, PDATA is recorded for a fixed PPULSE. Again, caution must be taken on the manufacturing line that there is no reflecting surface present. One method to prevent people or machinery moving around the test bench from impacting the measurements is to enclose the test bench in absorptive black material. Because of system noise, the OFFSET calculations should be determined by averaging a number of samples. The number of samples averaged will determine the accuracy of the offset as developed in DN33 and its appendices. The number of samples averaged is typically a multiple of the number of pulses.

Gain Calibration Procedure – Known Offset

If the offset was determined using the procedures above, then the gain can be calibrated by using a second single point calibration with a fixed target. With a fixed surface reflectivity (SR), the SR and proportion sign can be replaced with a distance correction factor (DCF). For this example the PPULSE is a fixed value. It is also assumed that the target is large so a $1/d^2$ optical response holds; otherwise, a square root function cannot be utilized.

PDATA/PPULSE ~ SR / (D * D) + OFFSET
PDATA/PPULSE – OFFSET ~ SR / (D * D)

Replacing the SR and the approximation with a Distance Correction Factor (DCF):

Distance = DCF * sqrt [1 / (PDATA - OFFSET)]
DCF = Distance * sqrt (PDATA - OFFSET)

For example, if the distance is 100mm and OFFSET are 100 counts, then:

DCF = 100 * sqrt (PDATA - 100)

Calculations using One Fixed Target and a Second with No Target Present

The first step of the procedure is to place a target in front of the device. This will establish the correct number of pulses and a proximity count value for a fixed target. Figure 7 shows an example of a systems allowing for accurate placement of a target.

Figure 7 – Example of Test System

The next step is to remove the target and record the proximity counts for an offset measurement with no target present.

As an example, if the measurements are 600 counts with the target present and 200 counts with no target, then the transfer function is calculated as follows:

OFFSET = 200
DCF = 100 * sqrt(600 – 200) = 2000

Calculations using Two Fixed Targets

Offset and Distance Correction Factor (DCF) can be calculated using two points on a curve. If we use 100mm at 600 counts and 200mm at 300 counts and 8 pulses, we can calculate the DCF and OFFSET as follows:

DCF = Distance * sqrt(PDATA– OFFSET)
DCF = 100 * sqrt(600 – OFFSET)
DCF = 200 * sqrt(300 – OFFSET)

Equating both sides:

100 * 100 * (600 – OFFSET) = 200 * 200 * (300 – OFFSET)
600 – OFFSET = 4 * (300 – OFFSET)
600 – OFFSET = 1200 – 4 * OFFSET
3 * OFFSET = 600
OFFSET = 200

Plugging OFFSET back into the original equation:

DCF = 100 * sqrt(600 – 200) = 100 * sqrt(400) = 100 * 20 = 2000

Calculating Detect and Release Thresholds

In order to have a system that will not chatter at the threshold point, the detect threshold and release threshold separation will be a function of the system noise and should be at least 6-sigma apart. For the TSL2771 set to 9 pulses, the standard deviation has been measured on an EVM to be 24 counts. To get a 6 sigma separation, the thresholds need to be 144 counts apart.

The next step is to translate the detect and release thresholds distances back to proximity counts and verify that they meet the 6-sigma criteria. Using the DCF and OFFSET from the example above and a detect threshold of 80mm and release of 120mm, the detect and release counts can be calculated:

Distance = DCF * sqrt [1 / (PDATA - OFFSET)]

Must Detect Threshold	Must Release Threshold
80 = 2000 * sqrt[1/ (PDATA – 200)]	120= 2000 * sqrt[1/ (PDATA – 200)]
$1/(80/2000)^2$ = PDATA - 200	$1/(120/2000)^2$ = PDATA – 200
PDATA = 825 (Detect Threshold)	PDATA = 478 (Release Threshold)

Since the detect threshold of 825 is 347 counts above the 478 count release threshold, the separation exceeds the 6-sigma requirement of 144 counts.

Final System Test

Final system test typically consists of a surface at the “must detect” threshold distance. Optionally a second surface would be at the “must release” threshold or the no target position could be used to verify that a proximity release has occurred.

These detect and release threshold will change depending upon test conditions. For example, in open air, the target distance may be 100mm with a must detect threshold of 80mm and a must release threshold of 120mm with a white target. However, when placed behind glass, such as in a cell phone, these parameters may change by 50% or more. In this example, this would reduce the target distance from 100mm to 50mm and the 8”x10” card could be reduce to a 4”x5” white card. If a gray card were used instead of a white card, the distance could be further reduced to 25mm with a 2”x3” gray card.

For this cell phone example, in the final manufacturing line, four stations could be provided: a calibration at 25mm, a calibration with no target, a test position with the target at 20mm and a test position at 30mm.

If the crosstalk, airgap, and ink variation can be held in tight control and a low value, the offset could be characterized and the second step in the process eliminated and the single point calibration used. If the device were assembled on a flex assembly and tested/trimmed at a subcontractor, then the first set could be eliminated. If the release point is not critical, the last target could be eliminated but the test step would still be required with no target.

Table 1 : Acronyms

Acronym	Description	Acronym	Description
ADC	Analog Digital Converter	IR	Infrared
AF	Attenuation Factor	LED	Light Emitting Diode
BGE	Background Energy	PDRIVE	Drive Current
CC	Crosstalk Coupling	PPULSE	Proximity Pulse
D	Distance	PDATA	Proximity Counts
DCF	Distance Correlation Factor	OC	Optical Crosstalk
DN	Designer's Notebook	OFFSET	Electrical Offset
ER	Effective Resolution	NOISE	Electrical Noise
GA	Glass Attenuation	SNR	Signal to Noise Ratio
GT	Glass Transmissivity	SR	Surface Reflectivity