Measuring Near-Infrared (NIR) Light Sources for Effective 3D Facial Recognition

Understanding NIR Sensing and Approaches for Measuring Radiant Intensity of NIR Emissions and Structured Light Patterns
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Introduction

Using near-infrared (NIR) wavelengths for three-dimensional (3D) sensing has taken off in the last several years with applications such as facial, iris, and gesture recognition, eye tracking, and automotive vision systems like LiDAR. The market for these optical sensing systems is projected to see a 22.7% to 24% compound annual growth rate (CAGR) in coming years, reaching as high as $3.8 billion in industry revenues by 2027.\(^1\)

Infrared light waves are invisible to the human eye, with “near-infrared” wavelengths ranging from approximately 700 nanometers (nm) to roughly 2,500-3,000 nm. Infrared and NIR wavelengths are commonly produced by LEDs (light emitting diodes) and lasers. Laser NIR wavelengths are commonly produced by Vertical-Cavity Surface-Emitting Lasers (VCSELs) for applications such as fiber-optics (telecommunication), automotive LiDAR, gesture recognition, and facial recognition. NIR facial recognition systems typically use 850 or 940 nm wavelength light.

NIR lasers provide greater accuracy than LEDs for proximity-sensing and autofocus applications. For example, lasers can be more precisely directed and reflected for facial and hand gesture recognition. Laser beams can pass through small-diameter openings due to their spatial coherence and focus, making them easy to integrate and manipulate through diffractive elements. Laser NIR enables 3D imaging solutions with superior depth measurement and mapping capabilities, for example, by using structured light (projecting light in a known pattern) for applications like facial identification.
This paper discusses how NIR light can be used in 3D facial recognition systems, and the methods for measuring and testing NIR emitters to help ensure they are accurate and effective for use in consumer electronics applications.

**Figure 3** - NIR facial recognition systems work by projecting a pattern of dots onto a person’s face. By reading how the dot pattern is reflected back, the system creates a 3D "map", which can be matched to a stored image to verify a user's identity.

**Flood Illuminators / Time of Flight**

One use of NIR LEDs in facial recognition systems is to establish the presence and/or distance of a user's face in daylight or darkness. The device emits a flash of NIR light (flood), and an NIR sensor receives signals reflected back from the object. The distance of the user's face is found by calculating “time of flight” (TOF), measuring the time it takes from the initial NIR flood emission to the return of the light's reflection back to the device sensor.

**Figure 4** - Some devices include a camera with a pulsed NIR light source, which will only accept reflected NIR light with the correct pulse. The return pulse is used for TOF.

**Diffractive Optical Elements (DOE)**

When structured light is used for NIR sensing, a single beam from an NIR laser is projected through an optical structure (a diffractive optical element, or DOE) to split the
laser into multiple emission points and cast an array of tiny invisible dots in a grid or fixed pattern onto a 3D object (such as a person’s face). When the light from each dot is reflected back from the object, an infrared camera measures how the pattern has been deformed and interprets the reflected light (via processing software) to determine the contours of the object. Facial recognition systems can have 30,000+ individual dots.

Figure 5 - For facial recognition, AI algorithms read the reflected pattern and infer depth and positioning of the object features, to construct a 3D “map” of the face, which is compared to known parameters (such as a stored image) to authenticate the user.

Unaffected by visible light, NIR sensors can accurately receive NIR reflections from a user’s face to interpret the 3D features unique to each individual. This NIR facial “map” is matched to a stored image for identification. NIR facial sensing ensures that you (and only you) have access to your personal information, bank account, car, or other protected media. Because NIR systems sense depth, they can’t be hacked with a 2D photograph, thus providing enhanced biometric security. NIR facial sensing can also be used to identify individuals for crime prevention, allowing law enforcement to spot target individuals even among a crowd.

Quality Considerations for NIR Sensing Systems
With the rapid adoption of 3D NIR sensing systems comes a growing demand for effective methods to measure the accuracy of NIR emitters. While 3D NIR technology provides more accurate facial recognition than previous 2D (photographic) methods, NIR systems can still be subject to performance issues. What if the NIR emissions are inaccurate in scope or intensity? What happens when low-output or poorly-placed emissions are interpreted by the sensing device?

Safety Considerations for NIR Sensing Systems
There are also safety considerations working with NIR wavelengths. They are invisible to humans, so do not trigger an “aversion response” (blinking or looking away from bright light). Yet NIR wavelengths can enter the eye and—with too much power (too much irradiation per area) or extended exposure—can cause damage to the retina or cornea. For safety reasons, facial and eye recognition systems that emit light in the NIR range must be carefully designed and tested to ensure they are emitting at correct levels.

For device quality, accuracy, and performance, manufacturers employ measurement methods to test the design and manufacture of NIR sources. Ideally, a measurement
system captures a variety of different characteristics such as emission uniformity, maximum power or intensity, radiant flux, emission distribution or spatial position—and it measures these parameters across the entire distribution area.

**Figure 7** - Visual representation of an NIR system being used for facial recognition. The device emits a DOE dot pattern (invisible to the user) that is cast on the face and can shine into the eyes.

### Challenges of Testing NIR Emitters

Facial recognition systems present a number of challenges for NIR performance evaluation. Capturing NIR light in angular space—especially when identifying up to 30,000 emission points produced by today’s smart device DOEs—is extremely difficult for traditional measurement equipment. The use of image-based NIR measurement systems (for example, a sensor-based radiometric camera) for NIR source measurement can limit this complexity by capturing and measuring all emission points produced by a DOE across a large spatial area.

To analyze the entire emission area that will cover a face, the testing device must quickly capture and evaluate a large angular distribution at close range. A wide-angle scope is needed to accomplish this, since the NIR-emitting device is typically positioned at a short distance (such as a smart phone held in a user’s hand).

An NIR light—like any light source—emits light in 3D angular space. As such, each dot in a DOE pattern may vary in intensity or position based on emission angle. Measurement of the NIR dot pattern must be performed at each emission angle to ensure that dot patterns are accurately projected and that each dot has sufficient intensity to be received and correctly interpreted by the device’s NIR sensor.

### Traditional Angular Measurement

Typically, a measurement system called a goniometer is employed to rotate an NIR light source in front of a photodetector or a camera to capture 2D images of emissions to evaluate radiant intensity at each angle (measured in watts per steradian, W/sr). This process is time-consuming, requiring thousands of rotations to capture a complete angular measurement. Furthermore, gaps in measurement can occur between goniometric rotations, missing irregularities in NIR intensity at certain points. Because
NIR emissions can be dangerous to human vision, all angular distribution points of an NIR source must be measured. Missing any point during measurement may mean missing an irregularly strong emission that could prove hazardous to the user, especially over time.

New Angular Measurement Solution
As an alternative to goniometers, a camera combined with Fourier optics eliminates the need for device rotation by capturing angular emission data directly from a single point. Lenses designed using Fourier optics principles enable connected imagers to characterize the full angular distribution of a light source, leaving no gaps in measurement. Advanced NIR measurement systems use Fourier optics to capture a full cone of data in a single image, to measure radiant intensity of an entire NIR light source. Identifying irregularities, peak emission, hot spots, and other issues over angular space (Figure 9).

![Figure 9 - Illustration of Fourier optics directing angular emissions of light through the specialized lens onto points on an imaging system’s image sensor, forming a 2D polar plot of the 3D distribution.](image)

DOE Dot Pattern Measurement Challenges
When evaluating NIR DOE emissions for facial recognition it’s imperative to assess every single dot for accuracy. Until recently, the method for measuring DOE emissions was limited to checking dot patterns for accuracy by mapping them against target patterns or coordinates (typically with the source cast against a screen or wall). However, this method does not dynamically adapt to new DOE patterns nor can it report precise radiometric data of the DOE emission points (such as radiant intensity, power, size), providing only dimensional evaluation (such as location).

Each dot in a facial recognition DOE array must be accurately positioned (angle, inclination, azimuth) and emitted with the correct radiant intensity (W/sr) to ensure it is properly reflected back and “understood” by the device’s infrared sensor. Manufacturers must control the position and output of each dot for the device to correctly map facial contours. For thorough evaluation of dot-by-dot performance and accuracy, the ideal measurement system should identify points of interest across the image, measure values for each dot in the pattern, and evaluate the accuracy of the pattern as a whole.
Traditional Dot Pattern Measurement

A traditional measurement technique for DOE-generated patterns is to cast the dot pattern on a wall or screen and then measure the reflection of the dots with an imaging system. This approach is used to verify dot position against a target pattern, or defined coordinates, offering a simple pass/fail evaluation based on pattern match. Intensity of the dot emissions cannot be measured effectively with this approach. Other limitations include a limited field of view, the requirement for a relatively large projection screen taking up a lot of space, and the fact that image resolution is potentially reduced due to diffusion by the screen material.

Figure 11 - Sample portion of a dot pattern before (left) and after analysis (right) using automatic dot detection in Radiant’s TT-NIRI™ software module.

Figure 12 - Close up of dots in TT-NIRI™ software, which measures maximum peak (strongest emitter), maximum peak location (inclination/azimuth), maximum peak averages, maximum peak solid angle, number of pixels as maximum peak point, spot power uniformity (between dots), total flux, and DOE flux, along with dot-by-dot measurements.

Figure 13 - Example of a Total Flux analysis of an NIR LED over angular space, shown in a false-color scale in Radiant Vision System’s TT-NIRI software. Radiant flux is a measure of radiant energy emitted per unit of time, e.g., Watts (joules per second).
Flood Measurement Considerations
As described above, some facial recognition systems rely on a “flood” function—a strong flash of NIR light used to detect a user’s face and determine focus distance. Like all NIR emissions, this flood function must also be tested to ensure it adheres to defined performance parameters. Irregularities such as hot spots or a fall-off of intensity around the perimeter need to be identified and corrected.

Figure 14 - Close up of the flood illumination source on a smart phone.

Figure 15 - Flood source emission cross-section derived from TT-NIRI analysis software.

Figure 16 - The angular distribution of an NIR flood projector, as captured in a single image by the NIR Intensity Lens and shown in false color (heat map) polar plot generated in TT-NIRI analysis software.
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Figure 17 - Radar plot and cross-section showing radiant intensity (as function of angle) of a near-infrared LED. Captured by a Radiant Vision Systems NIR Intensity Lens and shown in the TT-NIRI software platform for light source measurement. The Fourier-optic lens is calibrated to its connected imaging system, allowing it to accurately map angular emissions of the NIR device up to ±70° at once.

Radiant NIR Measurement Solution

The Radiant Vision Systems Near-Infrared (NIR) Intensity Lens system is an integrated camera/lens solution that measures the angular distribution and radiant intensity of 850 or 940 nm NIR emitters. The system uses Fourier optics to capture a full cone of data in a single measurement up to ±70 degrees inclination and 360 degrees in azimuth, giving you extremely fast, accurate results ideal for in-line quality control.

Manufacturers of 3D sensing technology can apply the NIR Intensity Lens solution for angular measurement of NIR LEDs, lasers, and structured light patterns produced by Diffractive Optical Elements (DOE). The lens is integrated with a Radiant Vision Systems ProMetric® Y16 Imaging Radiometer, and features ProMetric or TrueTest™ Software for intuitive system setup and customizable automated measurement sequences. Additional tests specific to NIR emission measurement are also in the TT-NIRI™ software module.

Test Suite for NIR Intensity Lens System

Part of the Radiant Vision Systems TrueTest™ Software family, the TT-NIRI™ software module provides the benefits of TrueTest Software to efficiently perform image-based measurements, but with application-specific tests to evaluate the accuracy of 850 or 940 nm NIR LEDs, lasers, and structured light patterns. Using the Fourier optics of the NIR Intensity Lens solution, TT-NIRI evaluates all angular emissions of a source in a single image, as well as all dots in a structured light pattern created by diffractive optical elements (or DOE).

A Radiant NIR test solution captures and processes data much faster and more consistently than a goniometric or spot measurement device. DOE dot source analytics captured by the NIR Intensity Lens and TT-NIRI software offer comprehensive radiometric data, which cannot be acquired using alternative methods such as casting a dot pattern against a wall or other Lambertian surface.

DOE Dot Source Analysis

Evaluating the accuracy of NIR emissions relies on radiometric measurements to determine the scope and intensity of NIR-emitting sources, as well as the angular...
position of precise emission points (dots) against defined tolerances. The Dot Source Analysis test can measure each and every dot in a DOE pattern to ensure that patterns are projected at the correct angle (inclination, azimuth) and intensity (W/sr).

TT-NIRI provides a comprehensive NIR test suite that allows users to define measurement parameters and pass/fail criteria for specific points of interest in an image. Data output for each dot can include a full set of data measured for each and every point. With some DOE patterns containing 30,000 or more dots, TT-NIRI provides data for each and every dot in the pattern, including location, intensity, peak, flux, and more.

Conclusion
A new generation of devices that use NIR emitters for 3D sensing demand new approaches to product quality testing to ensure the performance and accuracy of these invisible light sources. Applications such as eye tracking, facial recognition, and automotive LiDAR that are used on and around humans require rigorous testing to comply with internal and industry standards. Radiant’s near-IR measurement solutions characterize the output of NIR sources, providing manufacturers with data that may be useful when testing to these standards.

Advancements in NIR testing using radiometric measurement systems and specialized Fourier optics have been key. The Radiant’s NIR Intensity Lens solution offers the advantage of speed, size, and software for precise measurement of 3D facial recognition systems, performed more efficiently than traditional methods like goniometric solutions, and with minimal equipment.

References


Recognized for Innovation
Radiant Vision Systems received a Gold-level award for its NIR Intensity Lens solution at the 2019 Laser Focus World Innovators Awards, announced in November 2019. Radiant’s NIR Intensity Lens was recognized by an esteemed panel of judges from the optics and photonics community.
Use of near-infrared (NIR) light for 3D sensing applications such as facial recognition, eye tracking, and automotive LiDAR is growing rapidly. This paper discusses the challenges of measuring NIR emitters to ensure effectiveness and accuracy for facial recognition, and explains the benefits of an advanced Fourier-optic imaging solution for testing 3D sensing systems.