High-accuracy 3D scanning using Texas Instruments DLP® technology for structured light

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Introduction

Three-dimensional (3D) scanning is a powerful tool that acquires volumetric data leveraged for various metrology, inspection, detection and 3D imaging equipment. Designers frequently opt for structured light systems based on TI DLP® technology when they need very fast, high-accuracy scans with millimeter to micron resolution.

The emergence of 3D scanning systems

Simple two-dimensional (2D) inspection systems have been around for many years and generally employ the technique of lighting an object, taking a picture and comparing that image to a known "golden" 2D reference. 3D scanning adds the ability to incorporate volumetric information. Introducing z-dimension data enables measurements of volume, flatness or roughness. The ability to measure these additional geometries—not captured by 2D systems —is critical in industries such as printed circuit board (PCB), solder paste and machined part inspection. It is also used for medical, dental and hearing aid manufacturing.

Coordinate measurement machines (CMMs) were one of the first industrial solutions to gather 3D information. A probe physically touches an object's surface and combines the positional data from each point to create a 3D surface model (**Figure 1**). Optical methods such as structured light (**Figure 2**) later emerged for 3D scanning. Structured light is the process of projecting a series of patterns onto an object and capturing the pattern distortion with a camera or sensor. A triangulation algorithm then calculates the data and outputs a 3D point cloud, which becomes the data for various calculations in measurement, inspection, detection, modeling or machine vision systems. Optical 3D scanning is popular because it does not touch the object being measured and can be acquired very quickly, or even in real time.

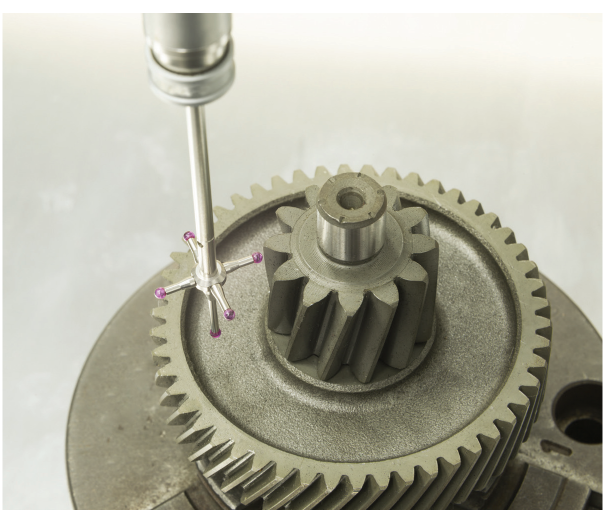

Figure 1. *Example of a coordinate measurement machine probe*

Figure 2. *Optical 3D scanning with structured light*

DLP technology enables fast, smart light pattern generation

For optical 3D scanning equipment, DLP technology is often used in systems as a source for structured light. A DLP chip is an array of highly reflective aluminum micromirrors known as a digital micromirror device (DMD). When combining a

DMD with an illumination source and optics, this sophisticated micro-electricalmechanical system (MEMS) can power various projection and spatial light modulation systems.

Designers frequently select DLP technology for structured light applications as the DMD is a flexible, fast, and highly programmable pattern generator. Unlike laser line scanners or diffractive optical elements (DOEs) with a fixed pattern set, it's possible to program numerous patterns with varying bit depth to a DMD. Structured light solutions using DLP technology are preferable for more detailed measurements that require accuracy in the millimeter or even micron range.

Applications leveraging 3D scanning systems

3D AOI

3D automated optical inspection (AOI) is a powerful technique used in manufacturing settings to provide real-time, in-line, decisive measurements relating to part quality. For example, 3D measurements for PCB solder paste inspection (SPI) are highly preferred since they measure the actual volume of solder paste deposited before component placement, helping prevent poor-quality solder joints (**Figure 3**). PCB manufacturing also leverages 3D AOI in-line after component placement, reflow, final inspection, and rework operations to maximize quality and reliability. As 3D inspection capabilities become more widespread, there are several emerging in-line factory inspection points choosing to take advantage of 3D AOI systems.

***Figure 3**. Illustration of PCB 3D SPI*

Medical

There has been explosive growth using 3D scanning technologies in the medical industry. Intra-oral scanners (IOS), for example capture direct optical impressions in dentistry (**Figure 4**). Micron-level 3D image accuracy is required to fabricate prosthetic restorations such as inlays, onlays, copings, and crowns. IOSs simplify clinical procedures for dentists, eliminate the need for plaster models and reduce patient discomfort.

***Figure 4**. Dental intra-oral scanner*

Another example of a growth industry is 3D ear scanning. Optical imaging systems capture precise 3D models of ears rather than using silicon ear mold impressions. 3D ear scanning also can enable the future of customization for consumer earbuds, hearing aids, and hearing-protection devices.

Industrial metrology and inspection

There are a multitude of different industrial metrology and inspection systems that have migrated to 3D optical-scanning techniques.

Optical 3D surface inspection microscopes are an example of an alternate option to offline CMM systems. These microscopes can measure more features for height, roughness, and computer-aided design (CAD) data comparison. Factories that build machined, cast, or stamped goods are another area embracing optical inspection. They can more easily

***Figure 5**. Robotic arm with 3D scanner*

and accurately measure x, y, and z dimensions for improved quality assurance. Inline 3D vision systems combined with robot arms have also emerged in the market (**Figure 5**). These robotic implemetnations can greatly increase speed and quality at automotive (**Figure 6**) and other production-line factories. Adding 3D inspection at specific stages of the assembly and production process can catch quality issues early, thereby reducing waste and rework. 3D scanning systems can even be implemented inside computer numerical controlled (CNC) equipment and 3D printers to enable real-time measurements during the manufacturing process.

***Figure 6**. 3D structured light scanning for automotive alignment and inspection*

Prosumer 3D scanners

Prosumer 3D scanners are portable tools offering professionals and amateurs the ability to capture complete details of real-world objects in a 3D data format (**Figure 7**). The data can then be used for product design, part engineering, 3D content creation, or as input to a 3D printer. For example, online retailers can 3D scan their products and present them online in a true, high-quality 3D model instead of 2D pictures. Gamers may 3D scan themselves and create their own avatars in a game.

***Figure 7**. Desktop prosumer 3D scanner*

3D biometrics identification and authentication

The use of biometric identification and authentication continues to increase. It is often used for securely locking or unlocking devices, security checks, and financial transactions. Using optical 3D scanning technology to capture face, fingerprint or iris biometrics can be a more secure means of identification and makes hacking and other attacks more difficult (**Figure 8**).

***Figure 8**. Fingerprint rendering resulting from a 3D scan*

System design benefits when integrating DLP technology

Whether inspecting PCBs for quality or making an accurate dental fitting, 3D scanning equipment using DLP technology for structured light can offer several compelling system benefits. The micromirrors on a DMD switch very fast—in microseconds—and can enable 8-bit phase shift rates greater than 1,000 patterns per second. This leads to high-speed data capture rates to achieve real-time 3D scans that are very useful for in-line measurements. High-speed DLP chips also offer programming flexibility to dynamically select and reorder patterns on the fly. This helps ensure the optimal pattern is applied to specific object locations or within specific fields of view, which assists in extracting the most accurate 3D information for analysis. Pattern duration and brightness can be controlled, ensuring the optimal amount of light is being reflected from the object and maximizing the dynamic range from the camera.

DLP technology can be combined with various light sources and is compatible across ultraviolet (UV), visible and near-infrared (NIR) wavelengths (**Figure 9**). This offers additional versatility for tailoring 3D scanning systems based on the target object's reflectivity. The flexibility to combine DLP chips with a broad choice of light sources and diverse camera options makes it possible to easily create one piece of equipment to measure multiple objects. It makes sense that automotive, industrial and medical companies look to DLP chips when designing next-generation 3D scanning equipment.

System integrators are able to innovate with flexible pattern control and new structured light algorithms when designing solutions using DLP technology. They can also optimize optical architectures to match key resolutions and illumination requirements for inspection scans. It is exciting that innovators can take 3D scanning to new levels using advanced programmability to optimize performance in all three of the spectral, spatial and temporal domains.

DLP Products portfolio considerations

TI's advanced light control portfolio offers DMDs and companion controllers imaging capabilities beyond traditional display. In particular, DMD chips span 363-nm to 2,500-nm wavelength range, have binary pattern rates up to 32 kHz and offer more precise pixel accurate control. Here's how DLP chipsets with advanced light control can benefit structured light systems.

DMD characteristics

- **Resolution**—DMD options range from 0.2 to 4.1 megapixels (MP) at the time of this publication. Larger 1, 2, or 4-MP DMDs tend to be used for systems requiring larger scan areas or bright ambient light situations. For instance, automotive 3D inspection requires large scan areas on bright factory floors during assembly and alignment process steps. DMDs less than 1-MP tend to be placed in compact handheld or tabletop equipment that requires portability or low power consumption.
- **Power**—The smallest chipsets use less than 200-mW of power consumption, making them a good fit for portable or battery-operated systems. Intra-oral scanning, for example, takes advantage of small DMD form factors with

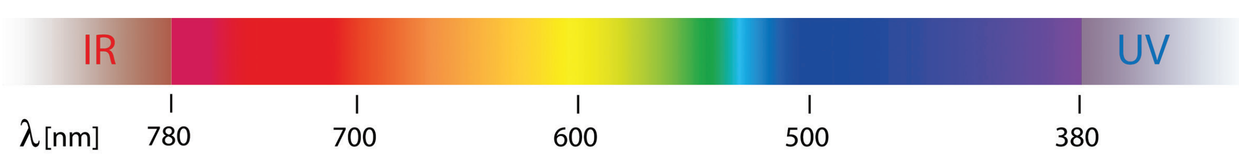

Figure 9. Light spectrum

low power consumption for battery-powered implementations.

- **Wavelength**—Users have the ability to adjust color and illumination intensity in a DLP technology-based system based on an object's reflective properties. This is made possible since a DMD can be combined with various light sources, including lamps, light-emitting diodes (LEDs) and lasers. There are DMDs optimized for UV (363–420-nm), visible (400–700-nm), and NIR (700–2,500-nm) use. For biometric 3D scanning solutions, near-infrared wavelengths are popular because the scans are not invasive. UV light is sometimes best for optimizing metals' reflective properties. For white light patterns, white LED optical engines are a desired power-efficient monochrome solution.

Controller characteristics

- **Pre-stored patterns**—DLP controllers provide convenient interfaces for reliable, high-speed DMD control. They support pre-stored structured light patterns without the need for an external video processor to stream patterns. Some DLP controllers can pre-store more than 1,000 structured light row or column patterns using one-dimensional (1D) encoding (see **Figure 10** for example). 1D patterns take advantage of using a single row or column and repeating that row or column across the entire array. Prosumer 3D scanner products often use 1D patterns to help reduce cost and increase scanning speed. More advanced controllers support up to 400 pre-stored 2D full-frame patterns (see **Figure 11** for example), which can be more tailored in x and y depending on the application needs or objects being scanned.

***Figure 10**. Examples of 1D patterns*

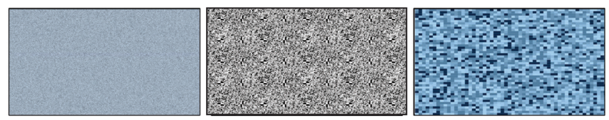

***Figure 11**. Examples of 2D patterns*

- **Pattern accuracy and speed**—DLP controllers are designed to display patterns suitable for machine vision or digital exposure and support variable high-speed pattern display rates up to 32,000 patterns per second with camera synchronization. These pattern rates are critical for highly accurate and high-speed 3D scanning systems.

From simple to complex systems, DLP technology offers customers incredible pattern flexibility when they design their custom structured light system hardware and algorithms.

DLP Products for 3D scanning

Texas Instruments offers a range of DLP chipsets to suit different 3D scanning requirements as shown in **Table 1** below. For the most current and complete list of DLP chips, see TI.com/dlp.

DMD	Micromirror array	Array diagonal	Optimized wavelength	Controller	Max pattern rate (binary / 8-bits)	High-speed pre-stored pattern display (2D or 1D)
DLP2010	854 × 480	0.20"	420–700-nm	DLPC3470	2,880-Hz / 360-Hz	1D only
DLP2010NIR	854 × 480	0.20"	700–2,500-nm	DLPC3470	2,880-Hz / 360-Hz	1D only
DLP3010	1280 × 720	0.3"	420–700-nm	DLPC3478	2,880-Hz / 360-Hz	1D only
DLP4500	912 × 1140	0.45"	420–700-nm	DLPC350	4,225-Hz / 120-Hz	2D
DLP4500NIR	912 × 1140	0.45"	700–2,500-nm	DLPC350	4,225-Hz / 120-Hz	2D
DLP4710	1920 × 1080	0.47"	420–700-nm	DLPC3479	1,440-Hz / 120-Hz	1D only
DLP5500	1024 × 768	0.55"	420–700-nm	DLPC200	5,000-Hz / 500-Hz	2D
DLP6500	1920 × 1080	0.65"	420–700-nm	DLPC900	9,523-Hz / 1,031-Hz	2D
DLP6500	1920 × 1080	0.65"	420–700-nm	DLPC910	11,574-Hz / 1,446-Hz	—
DLP7000	1024 × 768	0.7"	400–700-nm	DLPC410	32,552-Hz / 4,069-Hz	—
DLP7000UV	1024 × 768	0.7"	400–700-nm	DLPC410	32,552-Hz / 4,069-Hz	—
DLP9000	2560 × 1600	0.9"	400–700-nm	DLPC900	9,523-Hz / 1,031-Hz	2D
DLP9000X	2560 × 1600	0.9"	400–700-nm	DLPC910	14,989-Hz / 1,873-Hz	—
DLP9500	1920 × 1080	0.95"	400–700-nm	DLPC410	23,148-Hz / 2,893-Hz	—
DLP9500UV	1920 × 1080	0.95"	400–700-nm	DLPC410	23,148-Hz / 2,893-Hz	—

Table 1*. DLP chipset portfolio showing helpful 3D scanning specifications*

Summary

3D scanning using structured light is a desirable technique for the expanding markets and use cases requiring 3D optical measurement. Texas Instruments offers a diverse portfolio of DLP chips that can enable small, integrated scanning engines in personal electronics up to large, high-resolution pattern generators used in industrial inspection systems. DLP technology is a predominant technology choice for 3D scanning and machine vision solutions due to its tremendous versatility to customize patterns at very high speeds and its ability to pair with multiple light sources and wavelengths. This versatility also drives customer innovation and can push 3D scanning system capabilities to new limits.

Related websites

- Learn more about DLP technology.
- Evaluate DLP technology for 3D scanning with an evaluation module (EVM):
  - DLP 2010 Light Control EVM.
  - DLP 3010 Light Control EVM.
  - DLP LightCrafter 4500 EVM.
  - DLP LightCrafter 6500 EVM.
  - DLP LightCrafter 9000 EVM.
  - DLP Discovery 4100 Development Kit.
- Download these reference designs from the TI Designs reference designs library and speed product development using DLP technology schematics, layout files, bill of materials, and test reports:
  - DLP2010: Small Form-factor Structured Light Pattern Generator Reference Design for Portable 3D Scanners
  - DLP4500: Accurate Point Cloud Generation for 3D Machine Vision Applications using DLP Technology.
  - DLP6500: High-Resolution 3D Scanner for Factory Automation using DLP Technology.
- Contact optical design manufacturers (ODMs) for production-ready optical modules:
  - Pico chipsets – buy optical engines.
  - Advanced light control – optics and electronics.
- Contact design houses for custom solutions:
  - Pico chipsets.
  - Design service providers.
- Contact your local TI salesperson or TI distributor representative.
- Check out the TI E2E™ Community DLP Products Forum to search for solutions, get help, share knowledge and solve problems with fellow engineers and TI experts.

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