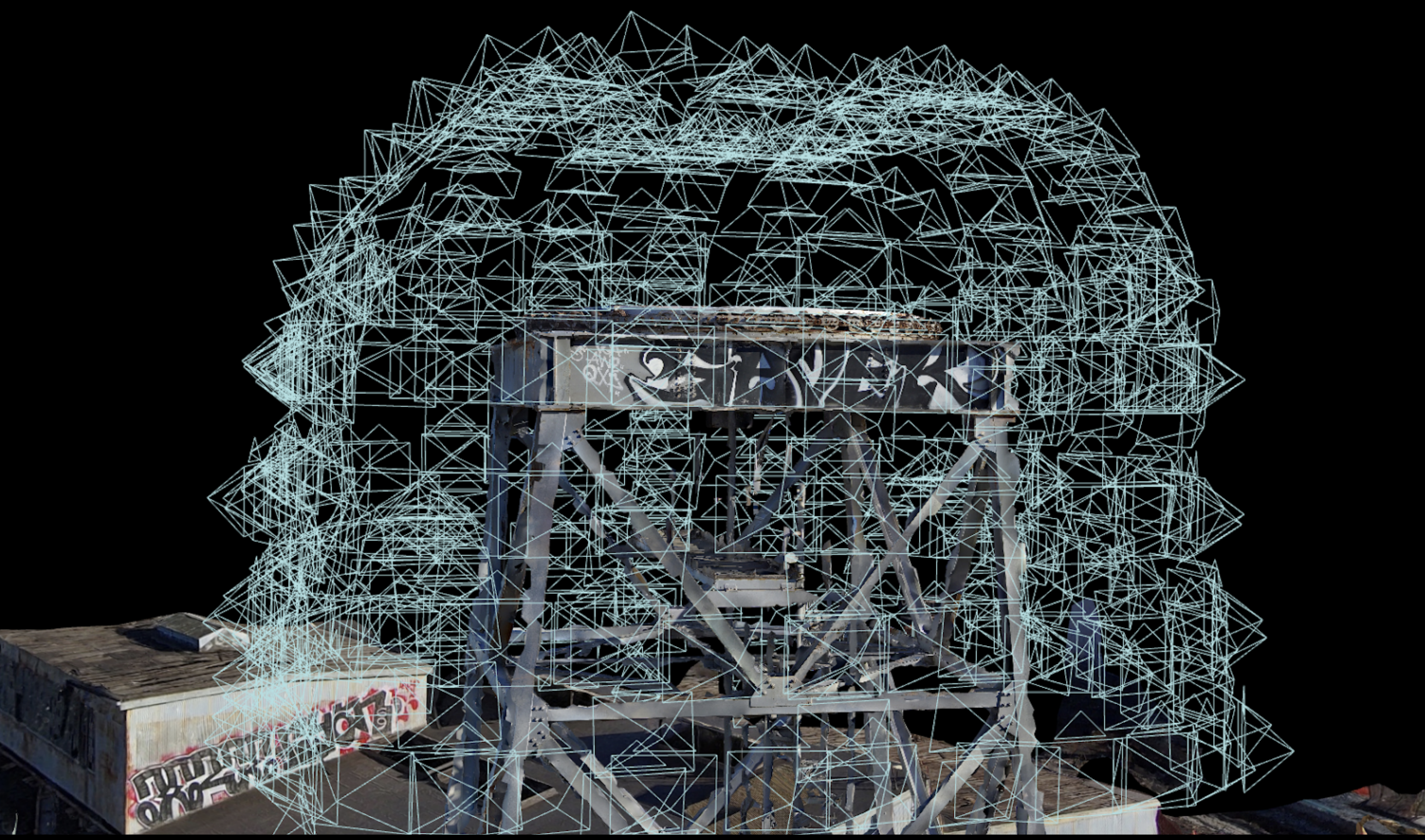
EBook

Enterprise Drone Inspection: Picking the Right Platform

Volume 1

Defining Data: Getting Decision-Quality Outputs From Drones

By Guillaume Delepine, Senior Product Marketing Manager



Prologue

With the growing number of enterprise drone options on the market today, operators face an ever-growing number of choices. Critically, the rise of autonomy offers an entirely new way to compare drones to each other. While the previous generation of manual drones were all equally limited to 2D waypoint or manual flight, autonomous drones can perform inspection missions with entirely different flight paths. These closer, more adaptive flight patterns render the old ways of comparing drones to each other based on rudimentary camera specifications, like the number of megapixels, outdated.

This paper is the first installment in the Skydio Inspection Data Series: a collection of white papers that will help enterprise drone operators from various industries make more informed decisions when choosing their enterprise drones. In this installment, we start by defining the goal: high quality datasets. But what makes a high quality dataset? Read on for our perspective, which is based on hundreds of customer interviews and combined decades of drone experience.

AUTHORS

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Guillaume Delepine is a Senior Product Marketing Manager at Skydio. In his tenure at the company, he previously led Skydio's efforts to serve first responders as Public Safety lead. Then, as Enterprise Strategy Manager, Guillaume contributed to the fundraising, planning, and hiring process that led to Skydio's recent announcements of a Series D fundraise at a valuation of over $1 billion USD, expanded roadmap, and growing executive team. Guillaume holds a BA from Princeton University, and took leave of the joint MPP/MBA program at Harvard University to join Skydio.

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Brian Richman is an Enterprise Product Manager at Skydio with almost 10 years of experience in drones. Brian works on realizing Skydio's vision for automated drone inspection and mapping by enabling levels of safety, precision, and data quality beyond what even the best drone pilots in the world are capable of. Before Skydio, Brian was the product lead for Airware's Mobile business unit, launching a pioneering end-to-end commercial drone configuration and flight software. Brian is also a former R&D team lead for the RQ-23 Tigershark program, with 700+ combined flight hours as a pilot, payload operator, and mission commander.

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Image Quality Test Engineer at Skydio

Russell graduated from University California Santa Cruz with a major in Photography. He spent the majority of his time there working on digital photography from his weekend job at Skydive Hollister. His love for action sport photography and his understanding of subjective review led him to a career at GoPro, where he was the lead Image Quality Test Engineer on the Hero 6 and 7. His role was to uncover all image quality issues and help find the path to a fix. Working closely with ISP Tuning Engineers, as well as Firmware Engineers, to get products out the door in the best shape possible. When Russell is not working, he spends the majority of his time outdoors either surfing, mountain biking, skydiving, or snowboarding.

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The Task at Hand

The fundamental task of inspection and mapping is to observe an asset or area and generate a report that gives observers enough information to make decisions for ensuing actions. These tasks are performed more widely than some might imagine. From construction, to infrastructure management, to commercial aviation, to first responders generating incident reports at crime or accident scenes, to populating virtual environments for applications like gaming—the task of observing and reporting to a remote audience is central to myriad workflows.

These processes have traditionally been performed by human inspectors who put themselves in harm's way—navigating unsure terrain, climbing ladders, rappelling from above, or facing explosive or radiation risk—to observe and document these sites. With the advent of drones, these crews can increasingly gather the visual data they need from a safe location by flying their aircraft into danger in their stead.

In many cases, drones can generate better data products than human operators can. Drones can capture vantage points that humans cannot reach to generate more exhaustive and detailed datasets. Further, through a process called photogrammetry, photos taken by drone can be stitched together to generate wide-area, stitched orthomosaic photos or 3D models.

3D models can be valuable tools to provide more useful inspection reports with much lower post-inspection effort, because all the photos from the inspection are indexed spatially rather than in the order they were taken. That allows consumers of the data—repair teams, project leads, or asset owners—to understand and execute on any actionable inspection findings faster than ever before. Additionally, 3D models facilitate precise measurements of features and artifacts observed in the images. But whether building 3D models or simply trying to generate useful photo datasets, there is little question that drones provide an opportunity to generate far superior datasets at a fraction of the cost and risk.

Equipping Teams for the Job

The benefits of using drones for these tasks have led inspection and mapping teams across the globe to adopt new technology that helps them get the job done safely. These teams encounter a wide menu of options when they start to research the drone industry, and their choice of platform makes a major difference in how they can build and scale their inspection program.

Manually operated drones are all-in on hardware, built around large and expensive sensors to capture quality data from long distance when flown by an expert pilot. There is, however, a new generation of drone technology, centered around autonomous flight. Autonomous drones employ a variety of hardware and software methods that work in concert to produce higher-quality data than manual drones can with even the most skilled pilots.

Below is a comparison of imagery from the Skydio 2 autonomous drone versus the manual DJI Mavic 2 Pro and DJI Phantom 4 Pro V2.0:

Image comparison - 2 meters away from an eye chart

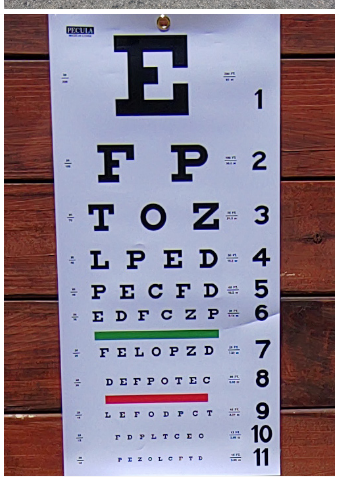
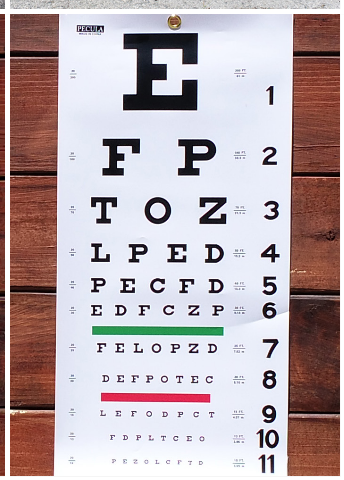
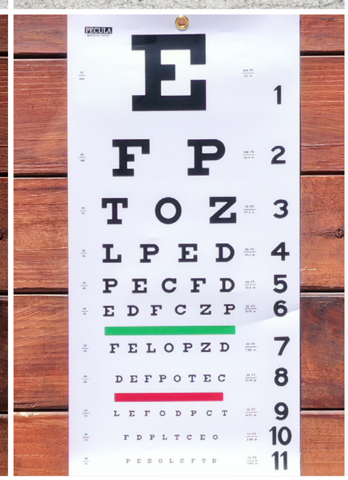
	Skydio 2 | 12 MP	**DJI Phantom 4 Pro V2.0** | 20 MP	**DJI Mavic 2 Pro** 20 MP
Original Images			
Close-up (zoomed to show same level of detail)			

Photo comparisons across the Skydio 2, DJI Mavic 2 Pro, and DJI Phantom 4 Pro V2.0. The top row shows the original images from these drones, taken at 6.5 feet (2 meters) away from the eye chart. The bottom row shows the same photos, zoomed in to show the same area. All photos were taken at the same time of day to isolate differences in camera hardware and tuning. Note that despite having fewer megapixels in its sensor, Skydio 2 produces a photo where smaller text is easier to read thanks to its superior image quality tuning software. Source: Skydio

Because manual drones were state-of-the-art through the 2010s, much of the market has been trained by manual drone manufacturers, trainers, and analysts to evaluate drones based on hardware specifications. With the rise of autonomous drones punctuated by the arrival of Skydio 2 in late 2019, there is a new alternative that needs to be evaluated on the merits of the inspection datasets it provides, not the hardware specs of the aircraft itself.

This industry-wide transition explains some of the industry's surprise at recent case studies from Skydio customers, including Accurate Drone Solutions and Aeronyde. In these case studies, companies explain how they have been able to achieve better inspection reports with the lower-cost hardware on Skydio 2 than they were able to create with top-of-the-line DJI drones, including the Phantom 4 Pro V2.0 and Mavic 2 Pro and Enterprise Dual. Through more intelligent flight patterns and precise tuning and integration of camera systems, Skydio drones help their pilots achieve superior results without needing to outfit their aircraft with expensive camera equipment.

In this eBook, we will explore best practices for defining what makes a good dataset for a given application. We will then compare the competing methods of achieving a strong dataset by drone, and provide data quality comparisons that can help decision-makers understand how and why autonomous drones provide better data than their legacy manual incumbents.

Defining Good Data Sets

On the surface, it seems simple to explain what makes a good dataset: it lets the consumer of the data see every surface of a structure as easily and clearly as if they were there in person. When it comes to measuring the quality of a dataset, however, various factors come into play. An inspection report on a clipboard must meet the bar in terms of detail and accuracy, and so must a software-enabled drone inspection report.

In this chapter, we discuss the factors and tradeoffs at play in capturing inspection datasets today. Not every inspector needs to generate a 3D model, but every inspector needs to be able to document scenes well enough to accurately assess the status of their asset.

The following parameters can help program managers measure the quality of their datasets:

- Resolution
- Photo Quality: Beyond Pixel Count
- Photo Location
- Relative and Absolute Accuracy

Resolution

The most commonly discussed measure of the quality of a dataset is resolution. The most common statistic in discussions of resolution is ground sampling distance (GSD).

Ground sampling distance is a metric designed around capturing data from high altitudes. It is a measure of the dimension of each pixel in a photograph on the physical surface being imaged. For example, a one-centimeter GSD would suggest that every pixel in the photo reflects one centimeter down on the ground. So, the same camera flying at low altitude would have a smaller (and, therefore, better) GSD than it would at a high altitude. Traditional inspection and mapping systems fly grid patterns that range from low altitudes up to 400 feet, so GSD can vary extensively. Operators care about GSD because it indicates the most precise level of detail that can be detected in the model.

A word of caution: GSD was probably the single most important metric for photogrammetrists in the 2010s, when the DJI Phantom was the dominant option for inspection and mapping. Today, however, operators have a greater variety of options to choose from—drones carrying cameras that differ by more than just field of view (FOV) and the number of megapixels in their sensors—and fly dramatically different routes to capture data, meaning they take photos from different distances. The following sections discuss the ways that camera tuning and position can have an even greater impact on the quality of the outputs than the ground sampling distance, which depends heavily on the number of megapixels in the camera's sensor.

Photo Quality

Inspection photos need to be clear enough that an inspector can see all the abnormalities that would be visible to them in an in-person inspection. Furthermore, the process of generating 3D models requires high quality photos for a reconstruction software engine to stitch together. Photos need to be high-resolution, well colored, and devoid of blur. Manual drones take the brute force approach to provide high quality photos by carrying expensive high-megapixel, mechanical shutter cameras.

High-megapixel cameras

Adding megapixels is the most expensive way to improve photogrammetric output. At $6,300, the 45-megapixel sensor on the M300 P1 camera costs more than four times the $1,599 Phantom 4 Pro V2.0 drone with its included 20 MP camera - and still needs to be mounted on an M300 drone. All other factors held equal, a higher megapixel count helps improve photo quality along metrics like resolution and noise, but it is not the dominant factor in a world where photos can be taken from closer in or farther away to generate photos at different resolutions.

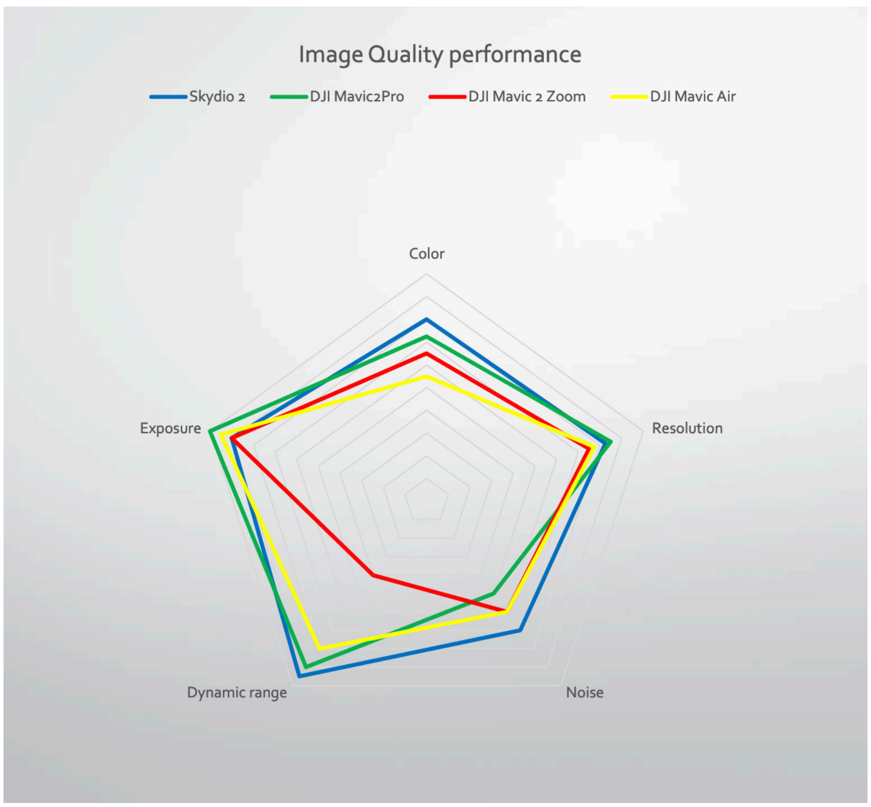
Mechanical shutter cameras

Mechanical shutter cameras expose all their pixels at the same time, as opposed to exposing pixels row by row like much less expensive rolling shutter cameras do. The intention is to reduce the rolling shutter effect, a distortion that occurs in rolling shutter photos when a scene is moving faster than the pixels are updating. However, almost all drones that advertise a mechanical shutter still use the sensor's rolling shutter underneath the mechanical shutter. This means that in order to realize the benefits of the mechanical shutter, you need longer exposure times which actually increases the risk of blur, especially in lower light scenes. But using a mechanical shutter to prevent blur in photogrammetry missions is like using a steamroller to clear a mole hill. The rolling shutter effect only starts to impact photos when the scene is moving at higher speeds—the classic example in the industry is a spinning airplane propeller—while the typical photogrammetry mission needs to be flown slowly for precision and safety. There are certainly limited situations where a mechanical shutter may help a job get done faster, like for large area surveys where it is helpful for the aircraft to cover the scene quickly, but the overwhelming majority of photogrammetry missions do not take advantage of the investment in a mechanical shutter.

While manual drone providers emphasize the importance of hardware factors, like high-megapixel cameras and mechanical shutter cameras, operators need to take a more holistic approach to make the best choice of aircraft for their photogrammetry missions. The software that tunes the camera can have an even greater impact on the quality of the photos than the mechanics of the camera itself. High resolution photos with inconsistent lighting will still generate a poor 3D model. The key factors at play are:

Sensor size

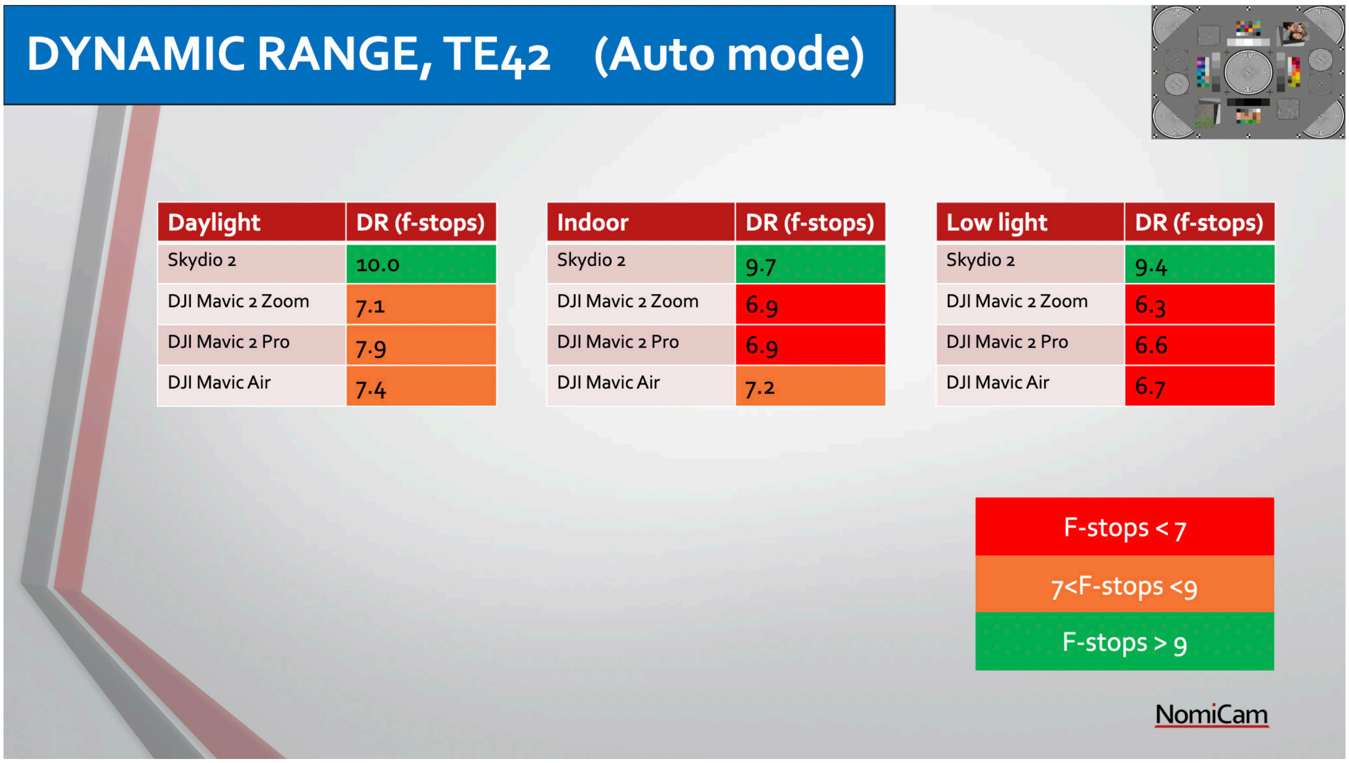
The size of the sensor module impacts the amount of light that is allowed onto the sensor. A larger sensor can carry bigger pixels and capture more light, improving photo capture in low-light environments, like dawn and dusk. While most photogrammetry flights are performed in full day lighting, it can be helpful to have a larger sensor to capture shadowy areas. Some manual drone vendors emphasize the importance of a 1-inch sensor for reducing noise. While this is certainly a helpful hardware feature, we will discuss later in the book why this is not the single dominant method of reducing noise. In a study by NomiCam, differences in lens and sensor housing quality, as well as software tuning, helped the Skydio 2 produce photos with less noise than its DJI counterparts.



In an independent study of image quality performance, which measures the quality of the image output instead of the number of pixels in the sensor, the 12 MP Skydio 2 camera provided equal performance to the 20MP sensor on the DJI Mavic 2 Pro. Source: Nomicam.

Dynamic Range

Dynamic range is the ratio between the lightest and darkest light level a camera system can capture in one image. Every object/surface brighter or darker than this ratio will be represented as black or white pixel in the final image - effectively carrying no information for a photogrammetric reconstruction. Cameras often carry a setting for High Dynamic Range (HDR), which can help ensure various parts of a photograph are exposed correctly, albeit with a small resolution tradeoff. For inspections of complex structures and scenes, a wide HDR ratio can help to preserve valuable information in darker areas, otherwise lost in total black and unusable for Photogrammetry. The resulting photos have more consistent details, coloring, increasing the likelihood that they can successfully be reconstructed into a 3D model and that the model looks realistic. However, not all HDR systems are created equal, and the software can be hard to measure with simple metrics. To truly assess the quality of an HDR system, we recommend looking at actual photo output to determine the quality level that satisfies your use case.



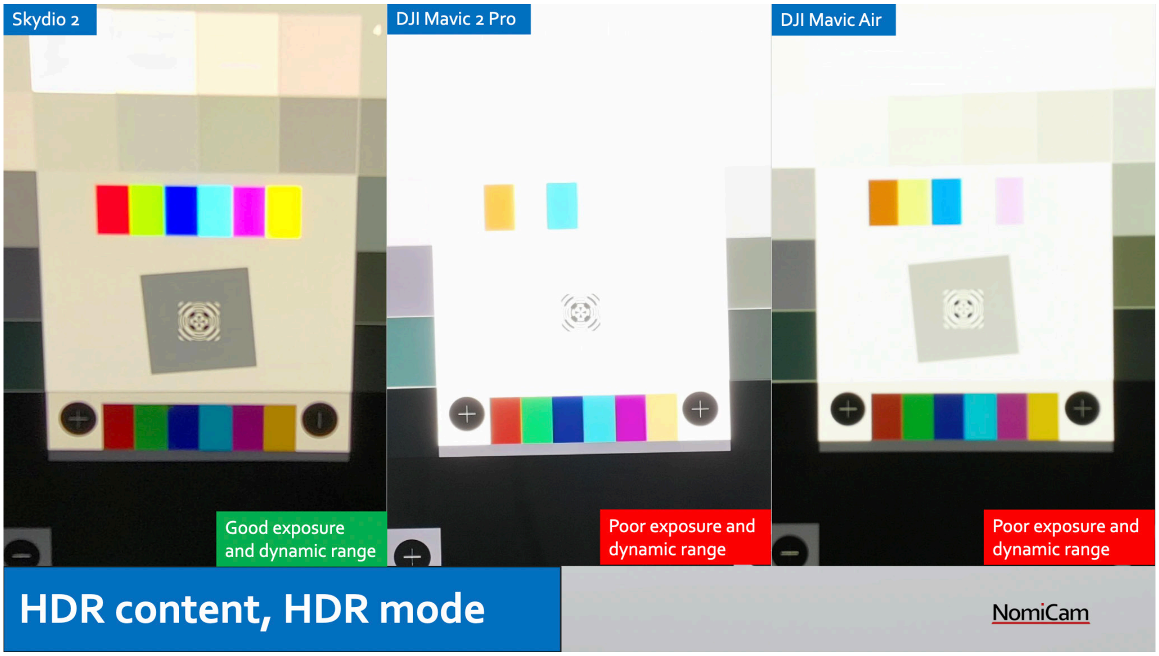
Daylight	DR (f-stops)
Skydio 2	10.0
DJI Mavic 2 Zoom	7.1
DJI Mavic 2 Pro	7.9
DJI Mavic Air	7.4

Indoor	DR (f-stops)
Skydio 2	9.7
DJI Mavic 2 Zoom	6.9
DJI Mavic 2 Pro	6.9
DJI Mavic Air	7.2

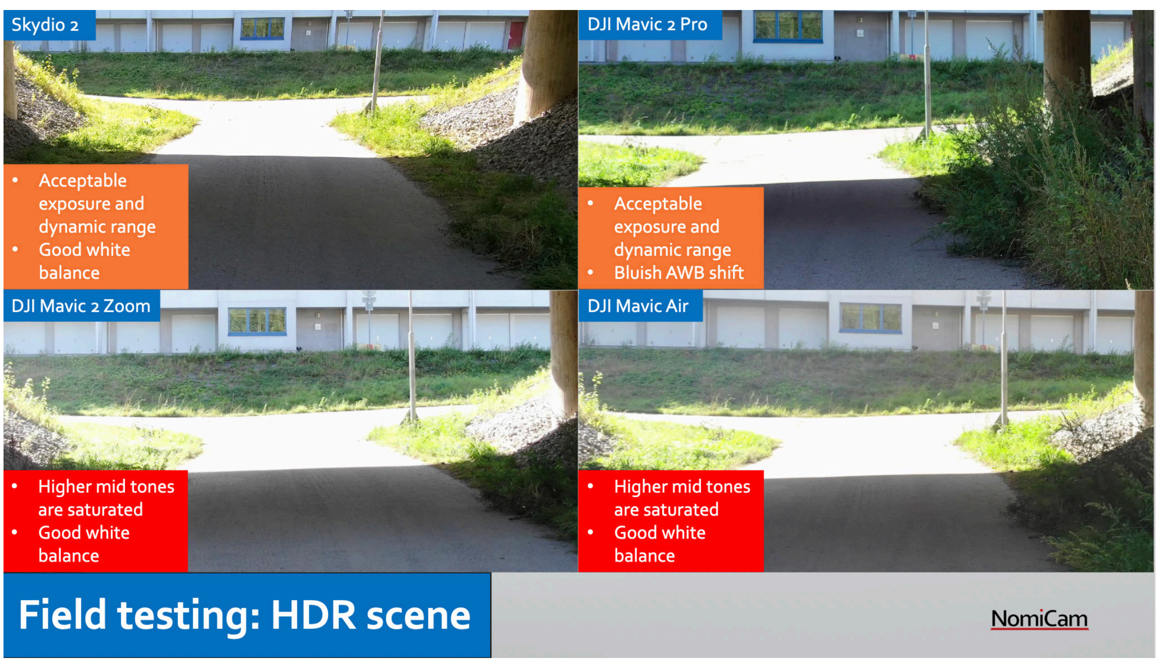
Low light	DR (f-stops)
Skydio 2	9.4
DJI Mavic 2 Zoom	6.3
DJI Mavic 2 Pro	6.6
DJI Mavic Air	6.7

Dynamic range can be measured in f-stops, each of which represents a factor of two in exposure. A higher f-stop number means a greater dynamic range. An analysis from NomiCam found that Skydio 2 had greater dynamic range in daylight, indoor, and low-light conditions than the DJI Mavic 2 Zoom, Mavic 2 Pro, or Mavic Air.

Below is an example of the difference between photos with well-tuned cameras and those with a hardware-centric approach—it is immediately apparent that the well-tuned version provides a richer view of the details in the scene.



In this laboratory comparison by NomiCam, the Skydio 2 camera more accurately reproduces the light and dark areas of the scene than does the Mavic 2 Pro or Mavic Air. Source: NomiCam.



In this real-life scene, the difference between strong and weak HDR systems is apparent from the photos. The photo taken by Skydio 2 preserves the colors in the scene more accurately than the Mavic 2 Zoom or the Mavic Air sensors. Source: NomiCam.

Photo Location

More important than having the right sensor is having the sensor in the right place. As this section will show, the locations of the photos used for a data gathering mission are a much bigger determinant of model success than even the quality of the photos themselves.

The ideal photogrammetry photoset includes photos taken from every angle relative to the surface, with approximately 80% overlap and sidelap, so that there is ample overlapping space for reconstruction engines to find common features and stitch photos into 3D models. However, in a three-dimensional world, this can require some advanced flying.

With manual drones, photos are generally captured using either top-down lawnmower patterns or manual flight. However, neither is optimal for generating a strong inspection dataset.

Obstacle clearance requires flying far away

Because manual drones cannot reliably avoid obstacles, top-down lawnmower patterns must fly far from the scene to maintain their Minimum Obstacle Clearance Altitude (MOCA), where they are above all features of the scene. The result is that photos are taken from hundreds of feet away, which is why many operators consider high-resolution sensor hardware a requirement. Even with that expensive hardware, there is no way to capture overhung parts of structures, like the underside of a bridge deck.

The requirement for long standoff distances trades off with resolution. As can be seen in the table below, Skydio 2 and X2 can capture the same GSDs as the DJI P4 RTK by flying a bit closer or farther from the scene. Flying with Skydio 3D Scan, the operator can input the distance the drone should maintain from the structure. A Phantom 4 pilot, however, has fewer options for up-close photos because the drone needs to retain a long safety standoff distance from the scene.

GSD at various fixed distance to surface between vehicles:

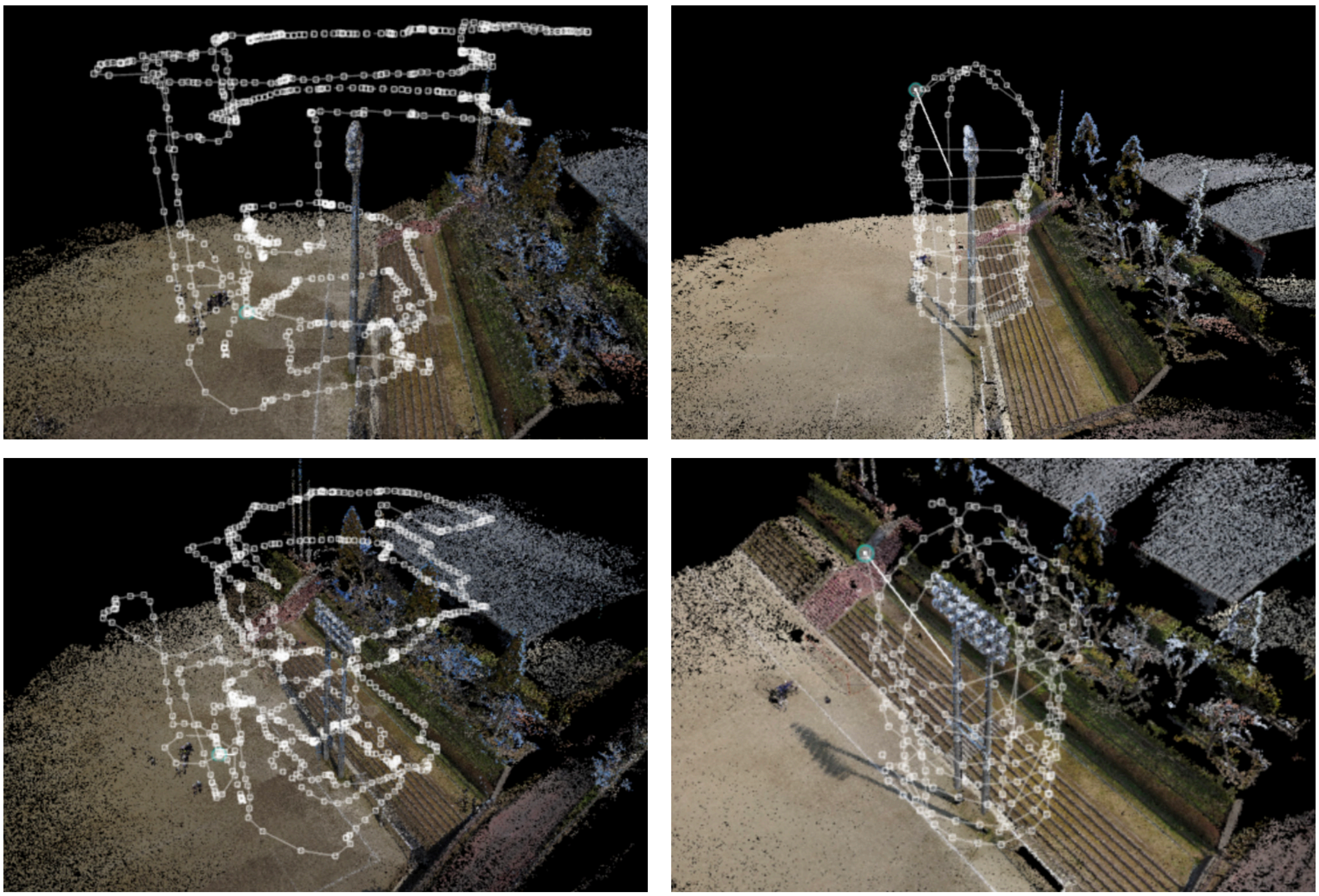
Distance To Surface (ft)	GSD (mm / pixel)		
	Skydio 2	Skydio X2	DJI P4 RTK
5	0.642	0.316	0.416
8	1.027	0.50[illegible]	0.665
12	1.541	0.759	0.998
15	1.926	0.949	1.247
20	2.568	1.265	1.663
30	3.851	1.897	2.494
40	5.135	2.530	3.325
50	6.419	3.162	4.156
60	7.703	3.795	4.988
70	8.987	4.427	5.819
80	10.270	5.060	6.650
90	11.554	5.692	7.481
100	12.838	6.324	8.313

Comparison of Skydio 2 and X2 (12 megapixel cameras) against DJI Phantom 4 Pro V2.0 (20 megapixel camera). Source: Skydio, DJI Camera Specifications.

Close-up manual flight is difficult and unreliable

To get closer to complex scenes, some skilled pilots fly their drones by hand to take photos up close to the scene. When they do, they face difficulties—beyond untrustworthy obstacle avoidance, manual drones depend on GPS and magnetometers for navigation. For inspection, however, that limits them from getting too close to the metallic and often overhung environments where missions happen.

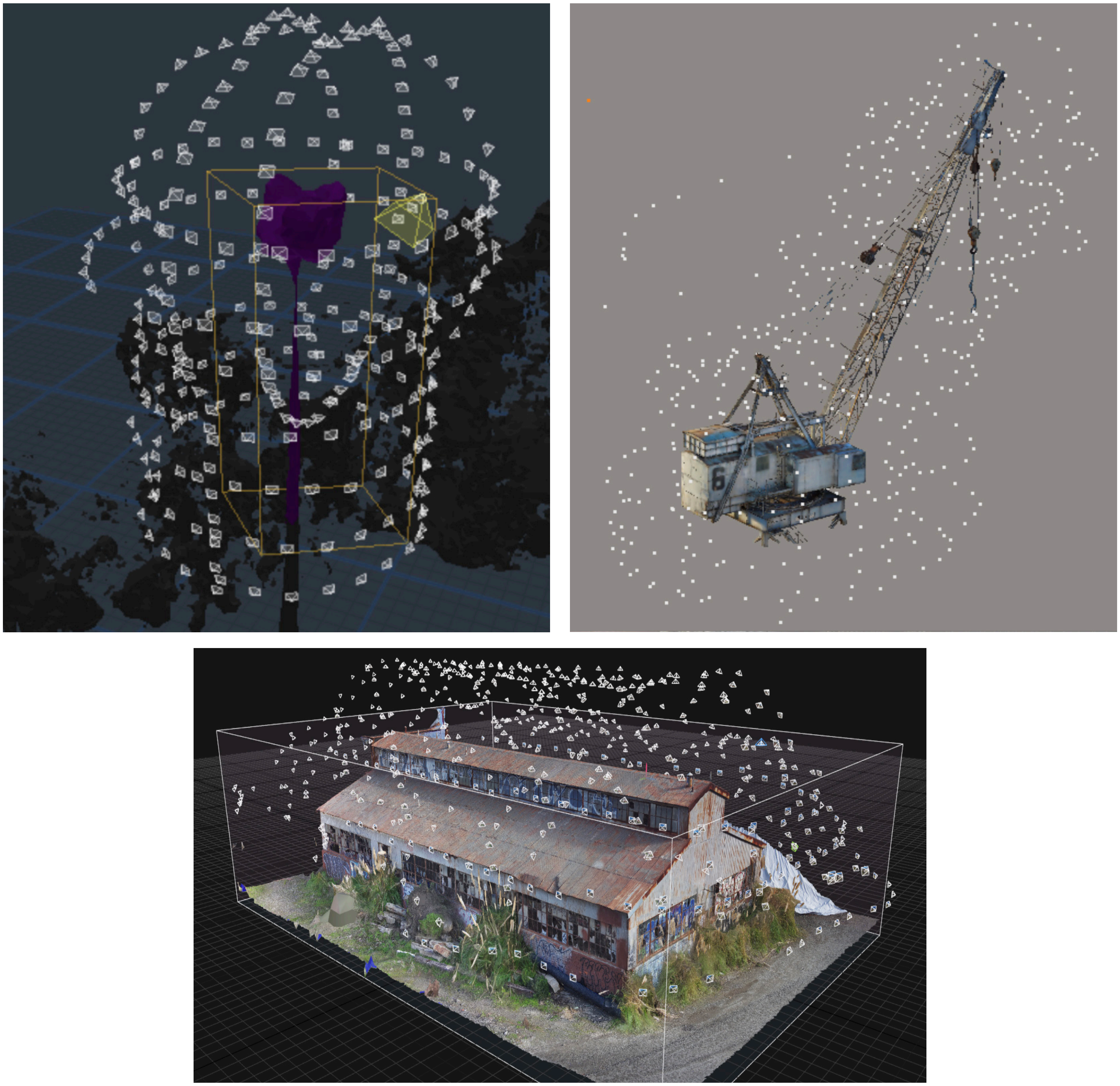
In environments where manual drones can fly, even the most expert pilot cannot reasonably be expected to generate a complete dataset with consistently overlapping photos of the scene. On a manual drone, a pilot simply does not have any way to know which parts have already been photographed, especially on a scene that can take over 1000 photos to capture. The result is either a complete (and expensive) excess of redundant data as a pilot attempts to capture all the required photos, or missing camera angles and inconsistent 3D models.



The flight pattern to the left was performed by an expert pilot with extensive experience inspecting tower structures by drone. The flight pattern on the right was performed by Skydio 3D Scan Adaptive Mapping algorithms. Even expert pilots struggle to generate as consistent data as autonomous drones can. Source: DoCoMo.

Autonomous drones can fly closely, reliably and efficiently

Autonomous drones today are capable of generating capture patterns that can adapt to any scene an operator assigns them. These Adaptive Mapping algorithms can even be tailored to offer the user control over the desired ground sampling distance, photo overlap, camera settings, and more to ensure efficient scans. Some examples of capture patterns are below, where it is evident that the drone is generating full coverage of the scene. Capturing images closer to objects helps photogrammetric engines to build 3D models easier and more accurately.



Skydio 3D Scan autonomously generates custom data capture plans for any scene the operator specifies. This helps the drone generate consistent, up-close imagery that maximizes photo quality with intelligent flight paths rather than expensive sensor hardware. Source: Skydio.

Relative and Absolute Accuracy

The final measure of model quality is accuracy of the reconstruction. 3D models can have two types of accuracy—relative or absolute.

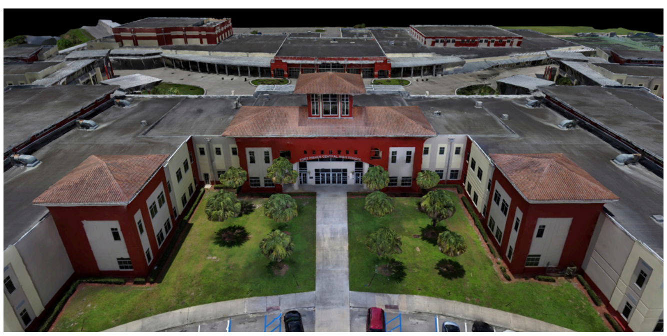
Relative, or local, accuracy means that the model has the same proportions as its digital twin in the real world—this is what allows analysts to take high-precision measurements of a scene using tools like Bentley ContextCapture or DroneDeploy. For most inspection use cases, this is the most important form of accuracy.

Absolute, or global, accuracy means that the latitude and longitude of the GPS points in the model are rectified against global GPS. This can be useful for some survey use cases—for example where roads need to line up precisely with each other.

Achieving Relative Accuracy

Relative accuracy requires a combination of photo-stitching in a photogrammetry engine, and precise GPS measurements. Relative accuracy is based on GSD, imagery quality, and the quality of the photogrammetry reconstruction software. Most photogrammetry software providers state a 2-3x GSD level of relative accuracy for their products, so if a pilot captures a GSD of 1mm, in a quality dataset and with the software performing without error, linear measurements of the 3D model should be within 2-3mm of real world values.

Relative accuracy is what generates a realistic-looking reconstruction. Below is a comparison from Aeronyde, a drone service provider in the Southeastern US, that shows the difference between weak and strong relative accuracy.



SKYDIO: In Aeronyde's controlled testing, Skydio 2 delivered a model with accurate geometry, vivid colorization, and consistent exposure.

DJI: By comparison, the same flight pattern with DJI generated inaccurate geometry, poor colorization, and inconsistent exposure.

Comparison of Skydio 2 and X2 (12 megapixel cameras) against DJI Phantom 4 Pro V2.0 (20 megapixel camera). Source: Aeronyde Corporation.

Achieving Absolute Accuracy

Absolute accuracy may be required when performing some tasks requiring survey-grade accuracy. Typically, it is more useful for mapping missions than asset inspections, where relative accuracy is all that is required. To achieve absolute accuracy, operators have to use additional technology not typically included with the most affordable enterprise drones (such as Skydio 2 and X2). These technologies include Real-Time Kinematic (RTK) GPS, Post-Processing Kinematic (PPK), or ground GPS referenced ground control points (GCPs).

To generate accurate GPS readings, leading manual drone manufacturers offer RTK GPS, which helps provide globally accurate GPS readings. While these tools add accuracy, they also add cost and additional steps for the operator.[1] With autonomous drones, however, the more complete datasets enable higher levels of relative accuracy directly from the photo set.

GCPs are positioned around a scene where they will be captured by the photographs, and the operator records their precise GPS position with additional high precision GPS devices, so that a reconstruction engine can rectify the GCP against both the rest of the scene and the global frame. GCPs are a less expensive way to improve absolute accuracy, but can require the operator to walk around the scene to implement and log GCPs, a process that adds time (and therefore cost) to the drone operation.

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[1] DroneNerds. "DJI Mavic 2 Enterprise Advanced RTK Module." Accessed: 19 May 2021. https://www.dronenerds.com/products/drones/enterprise-drones/mavic-2-enterprise/dji-mavic-2-enterprise-advanced/dji-mavic-2-enterprise-advanced-rtk-module-m2eartk-dji.html

Skydio Solutions for Inspection

After reading the previous chapters, it is our hope that you feel more equipped to make a decision regarding your selection of drones. As you take this knowledge into the field to evaluate the available technologies, below is a concise summary of the components that make up the Skydio solution for industrial asset inspection. Your Skydio sales and solutions engineering teams can help you determine which options are right for your program and make a plan to implement them.

Skydio 2

An entry-level drone to introduce autonomy to inspection workflows. Features a 12MP camera, and six 4K color sensors used to support Skydio Autonomy enabling true 360° obstacle avoidance in every situation and up to 23 minutes of flight time. Backpack portable and easy-to-use, Skydio 2 can be provided to any inspector to start taking advantage of aerial data.

Skydio 2

Skydio X2E

Pairs the breakthrough Skydio Autonomy™ engine with a ruggedized airframe that features a color or optional dual color/thermal sensor, long-range operations, and extended battery life for up to 35 minute flight time. Core autonomy capabilities of the drone previously described in this paper include **360° Obstacle Avoidance**, **Object and Scene Recognition**, and **Skydio Visual Navigator**.

Skydio X2E

Skydio Enterprise Controller

Ground control for X2E is enabled via the Skydio Enterprise Controller, which was designed from the ground up for pilots with demanding operating requirements. Ground control software is natively delivered via the Skydio Enterprise App.

Skydio Enterprise Controller

Skydio Autonomy Enterprise Foundation

An add-on software package that augments the core autonomy engine. It's designed to assist the pilot through software capabilities that enhance flight control in obstacle-dense environments. Key features of this package previously presented in this paper include **Close Proximity Obstacle Avoidance**, **Vertical View**, and **Visual Return to Home**.

Skydio Autonomy Enterprise Foundation

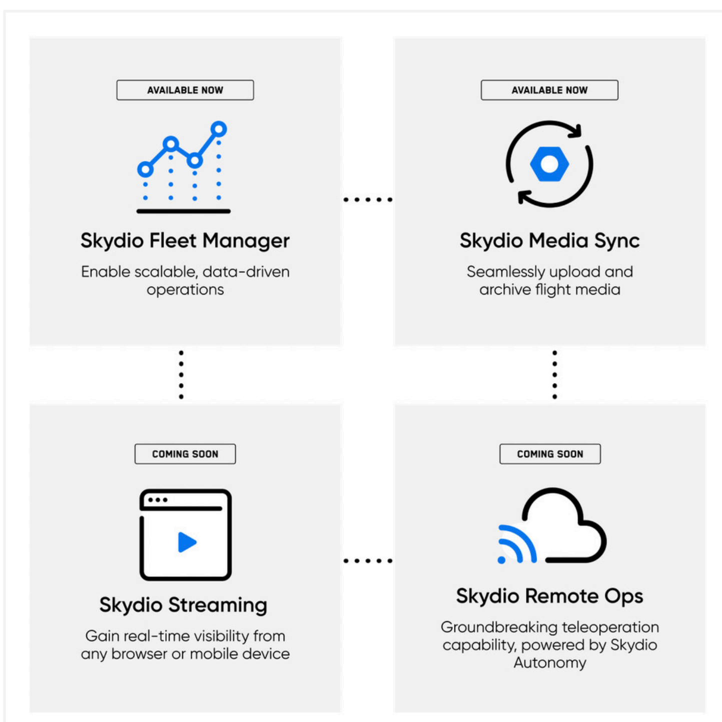
Skydio 3D Scan™

The first-of-its-kind adaptive scanning software built on top of Skydio Autonomy. 3D Scan allows the drone to automate the data capture process needed to generate 3D models with comprehensive coverage and ultra-high resolution, so that crews can perform higher quality scans in less time and with minimal pilot training.

Skydio 3D Scan

Skydio Cloud

Skydio Cloud serves as a foundation for autonomous connected flight operations as well as API-based integrations with our partner ecosystem. It includes Skydio Fleet Manager and Skydio Media Sync, currently available in limited early access, which help distributed fleets manage their operations and data more effectively than they can with spreadsheets and SD cards. Skydio Streaming and Remote Ops are both coming soon, and allow for real-time monitoring and execution of drone operations through the cloud.



Skydio Academy

Delivered online, or in-person, in both self-paced and instructor-led configurations, Skydio Academy provides flexible options for your pilots to achieve the **Skydio Professional Operator (SPO)** and **Skydio Expert Operator (SEO)** certifications that can help a program manager manage and track core competencies across a distributed pilot fleet.

Skydio Professional Operator (SPO)

Certifies **foundational knowledge** about Skydio aircraft, preflight, launch, flight skills, landing, postflight, maintenance, and troubleshooting.

Skydio Expert Operator (SEO)

(requires Skydio Professional Pilot certification)

Certified **real-life flight skills** to safely and efficiently operate Skydio aircraft and software. As an SEO, you will be ready to take flight with complete confidence.

Conclusion and Looking Ahead

The data product is the most important output of a drone program, and producing a useful dataset can help a drone program reach scale within a large organization full of consumers of that data. Therefore, we encourage drone operators to work with their downstream colleagues to make sure that the drones they purchase can produce sufficient datasets to meet the precision requirements. The concepts in this white paper can help to provide a framework for evaluating the dataset, which is step one in evaluating the drone.

In the next installment of the Inspection Data Series, we will be looking at our first industry deep-dive, to see how the construction industry needs to think about data requirements and can structure its drone programs. Stay tuned for the next chapter!