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# Color calibration of unmanned aerial system digital still cameras

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## Abstract

*There are currently no standards for characterization and calibration of the cameras used on unmanned aerial systems (UAS's). Without such standards, the color information in the images captured with these devices is not meaningful. By providing standard color calibration targets, code, and procedures, users will be empowered with the ability to obtain color images that can provide information valuable for agriculture, infrastructure, water quality, even cultural heritage applications.*

*The objective of this project is to develop the test targets and methodology for color calibrating unmanned aerial vehicle cameras. We are working to develop application-specific color targets, the necessary code, and a qualitative procedure for conducting UAS camera calibration. To generate the color targets, we will be following approaches used in the development of* ISO 17321-1: Graphic technology and photography — Colour characterisation of digital still cameras (DSCs) — Part 1: Stimuli, metrology and test procedures *as well as research evaluating application-specific camera targets. This report reviews why a new industry standard is needed and the questions that must be addressed in developing a new standard.*

## Introduction

The use of unmanned aerial vehicle-based imaging systems is becoming an important tool in many agricultural and industrial applications. But, for these devices to be truly useful, effective calibration methodologies and targets are required. There is currently no standard approach for characterizing and calibrating unmanned aerial system cameras. Without such standards, the images captured with these devices provide no viable color information. Standard color calibration targets, code, and procedures, will enable UAS-borne cameras to obtain images that provide valuable information for agriculture, infrastructure, water quality, even cultural heritage applications. A standardized calibration paradigm will also provide those interested in assessing the relative capture quality of UAS cameras (independent laboratories or UAS magazine and e-zines, for example) a structure for doing so.

The objective of this project is to develop an unmanned aerial vehicle camera color calibration methodology including application-specific color test targets, code, and procedures. To generate the targets and calibration procedure, we will be guided by the approach described in *ISO 17321-1: Graphic technology and photography — Colour characterisation of digital still cameras (DSCs) — Part 1: Stimuli, metrology and test procedures* [1] along with other research evaluating application specific test targets [2-7]. This paper describes the need for a new standard calibration procedure for unmanned aerial systems and what such a standard should entail. This includes the questions that it needs to answer and some of the possible applications to which it would be applied.

## Why a new International Standard for the Calibration of UAS-based Cameras?

*ISO 17321-1: Graphic technology and photography — Colour characterisation of digital still cameras (DSCs) — Part 1: Stimuli, metrology and test procedures* [1] covers the characterization process for digital cameras. Why not just apply this standard to the cameras used on unmanned aerial systems (UAS's)? Because the devices used on these systems, for example as shown in Figure 1, and their applications differ from those included in the scope of this current International Standard in several important ways. Perhaps the most significant difference is that the calibration process will be taking place *in situ,* with calibration targets literally placed in the field for capture during the course of the imaging run, as shown in Figure 2. For the information collected by the UAS's to be useful, the illumination present as the system images a given area and its impact on the captured samples must be understood and taken into account. As is apparent from Figure 2, shadows from cloud cover and surrounding trees and buildings may have an impact on the measurements made.

Unlike the case of calibration of DSCs, where the illumination can be carefully defined and controlled, the illumination for calibrating UAS's is not defined, beyond being daylight, example relative spectral power distributions shown in Figure 3. And it cannot be defined because it is impossible to control the lighting conditions. Instead, the illumination should be measured in conjunction with the imaging run, and monitored for any changes. An example of an imaging run is provided in Figure 4. The calibration target can be imaged multiple times, for example at the beginning and end of each imaging run, to characterize the variability due to changes in illumination such as shifting cloud cover, as well as to inherent system variability and to motion.

Additionally, verification data can be taken multiple times within the run. Measurements could be made each time the UAS reaches the edge of the area being imaged. For example, in the flight plan illustrated in Figure 4, measurements could be made each time the UAS reaches the western edge (river side) of the imaging area. The number of calibration target captures made may also be dependent on the variability of the initial measurements. Understanding the impact of measurement variability on the quality of the image captures is part of the research being conducted in developing the proposed standard. Establishing the number of calibration target captures made may also be affected by the presence of an onboard luminance level sensor. If this sensor indicates that the ambient light level changes significantly, additional captures may be required. What 'significantly' means remains to be defined as part of the research project. In determining the number of captures made of the calibration target, it is important to remember that users are interested in maximizing the area being imaged in a given flight plan, since the flight time of the UAV is limited by the battery capacity. The size of the captured area is negatively impacted by repeatedly returning to the calibration target. While it is essential to ensure that the color image information captured is meaningful, the calibration must be done without severely impacting the area that can be imaged on a single UAS run. This trade off needs to be understood.

Another important difference is that the UAS is moving when it is capturing information, although these systems are typically capturing still images (in formats including JPEG, TIF, proprietary RAW, or ENVI). Artifacts that result from this motion must be taken into account. The calibration patches must be large enough so that the impact of edge smear is minimized or eliminated. The patches also should be square to reduce the impact of target orientation. Along with the fact that the UAS is moving, it is important to note that it is moving above the target scene, as well as the calibration target, in a range of 50 to 400 feet, depending on the resolution needed. This added distance means that the patches need to be quite large. There is, therefore, not as much real estate available for the plethora of patches often used in calibrating digital still cameras. Development of a test target for UAS camera calibration thus requires much greater selectivity. In addition, while test targets for conventional photography are particularly concerned with the reproduction of skin colors and blue sky, these are not relevant to most UAV applications. Instead, the UAV applications are concerned with more scientific measurements of vegetation, soil, and man-made structures such as pipelines and roofs. Therefore, the development of appropriate color patches is a key area of research. Additionally, with these devices in flight above the targets, the imaging geometry is considerably different for UAS's capturing target information from the air relative to digital still cameras capturing mounted targets in a laboratory, as shown in Figure 5. UAS's are much further from their targets and the illumination provided is inherently non-uniform over time and may lack spatial uniformity as well.

The intended use of the images captured by DSCs and cameras incorporated in UAS's represents a key difference between the application of these devices. Generally, images captured by digital still cameras are being used to create scene reproductions for memory or communication purposes. We take pictures of our kids to share with family who live far away or take vacation pictures to share with friends or to browse during the depths of winter. Images captured by UAS's, by contrast, are generally used for actionable information. With all of the added complications of UAS camera capture, this represents one simplification relative to digital still cameras. There is such a thing as getting it right, with UAS camera calibration, as opposed to the case where we are making it beautiful. We know that beauty is in the eye of the beholder, meaning that there is no one 'right' answer. Because UAVs are used to make measurements, rather than to generate an attractive reproduction, they do not normally use proprietary color reproduction algorithms designed to create beautiful reproductions. However, getting it right for applications involved in UAS imaging can require that information be captured accurately for a much greater spectral range. UAS cameras capture imagery much further into the near Infrared (NIR) region of the spectrum then is necessary in the case of images being captured for conventional photography – indeed this NIR region is nearly always filtered out by an IR blocking filter. This represents another key difference between the two systems in that the output for the DSC is a scene reproduction, while the UAS camera output is a displayed visualization of the information captured. An example of UAS output is illustrated in Figure 6.

Because UAS borne cameras will be calibrated outdoors, lightfastness will be a key concern for the targets developed for this purpose. A significant piece of the research conducted in developing this proposed calibration standard will be centered on determining the appropriate materials for the targets. Along with being lightfast, they must adequately represent the plant matter or other materials being imaged. This means finding calibration target pigments and materials that represent what is being captured as far across the spectrum as is possible. The calibration target materials must also have no or limited fluorescence, since the substances being imaged generally do not fluoresce, and specular reflection. The target should be as matte as possible. Additional considerations in the target design include physical stability, portability, and surface texture. Research on calibration target texture will be another important piece of the work in developing this proposed standard.

*Figure 1. An unmanned aerial system prior to an imaging run and a multispectral sensor*

*Figure 2. Calibration targets can be impacted by nearby trees (or buildings) and clouds*

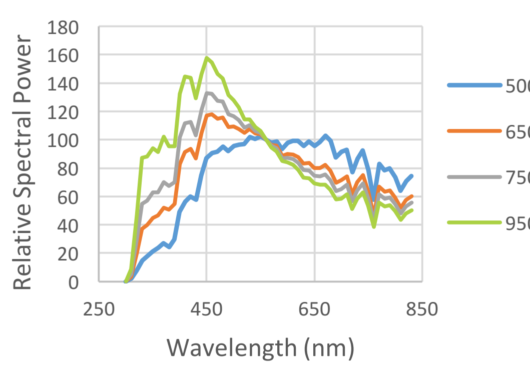


*Figure 3. Example Daylight relative spectral power distributions for a range of correlated color temperatures (CCTs).*

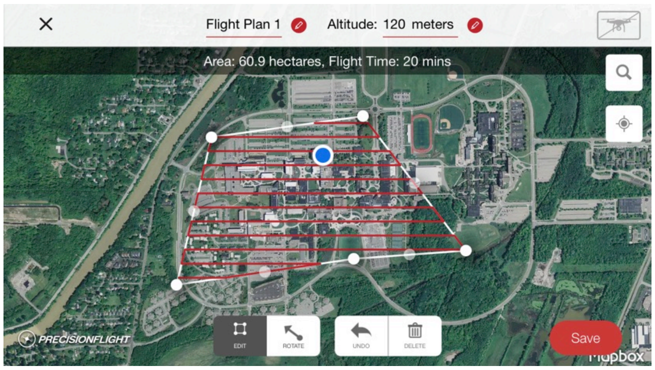


*Figure 4. Example unmanned aerial system flight plan. Note the altitude of 120 meters.*

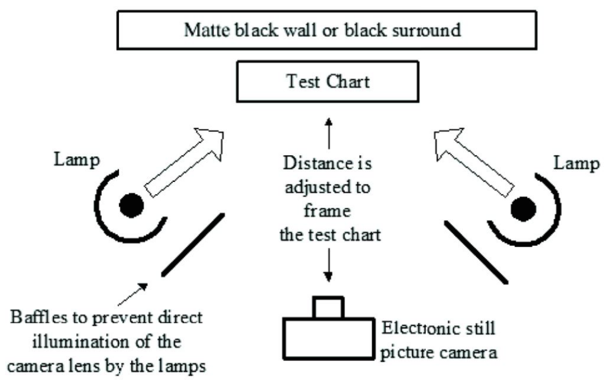


*Figure 5. Schematic of the test setup for imaging a test chart as part of the digital still camera characterization process.*

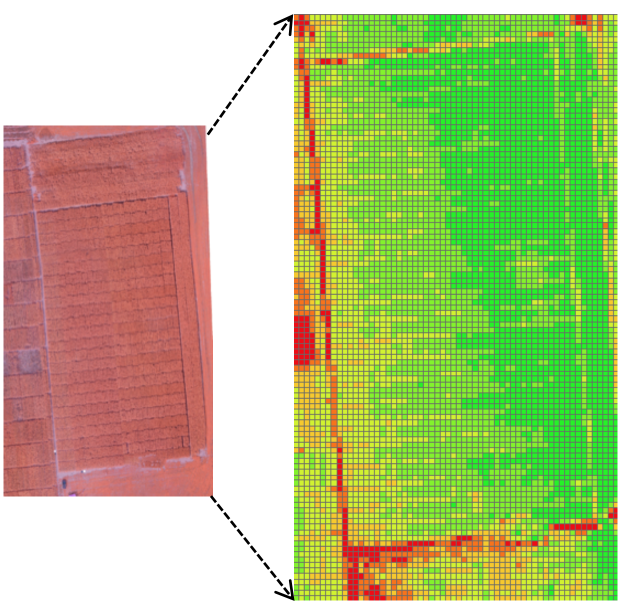

*Figure 6. Example of the visualization of unmanned aerial system camera output for the imaging of an agricultural field. The red regions are where there are issues with crop health.*

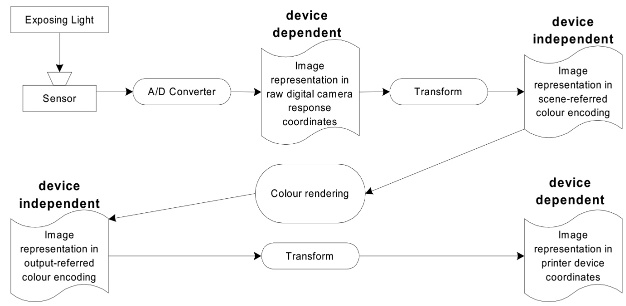


*Figure 7. Generic image workflow for digital photography, from [8].*

## Framework for developing an unmanned aerial system camera calibration standard

While the existing standard does not apply directly to UAS-based cameras, it does provide a framework for building a new standard for calibrating these systems. The basic workflow for both digital still cameras and UAS-based cameras can be represented generically, as shown in Figure 7, for example, with the caveat that the UAS camera output will be a visualization rendered for the appropriate output device. Elements of the digital still capture standard, ISO-17321-1, that will be incorporated in the development of a standard for UAS cameras include:

- capture multiple images of the target at the start and end of an imaging run to document variability
- use the central 50% of the area of each patch
- the calibration targets must be self-supporting and flat
- fluorescent materials should be avoided
- a variety of neutrals is helpful, evaluation of the opto-electronic conversion function will be of interest
- surround the target with a black mask, as in Figure 5, with attention to problems that may be introduced as a result of the motion of the UAS-based camera

Another important similarity for calibrating the two types of cameras is that both benefit from having targets composed of colors that are spectrally representative of the scene being captured. This has been known since the development of the first commercial test target, which incorporates patches designed to, as closely as possible, match the spectral content of photographically important colors including skin, sky, foliage, and a particular blue flower known to be particularly difficult to reproduce. [2] Since this time, additional work has been undertaken to generate color test targets for specific applications including agriculture [3], cultural heritage [4,5], originals having small gamuts [6], and water quality [7]. Using patch colors that are spectrally similar to the scene helps to reduce the impact of metamerism from changing light sources and 'observers' (human and camera) [4]. For UAS's, one can imagine, for example, including spectrally representative colors of healthy and unhealthy crops in agricultural applications or even a section of roofing materials for infrastructure inspection. The spectral and colorimetric information for all patches should be included with commercially produced targets. In using the spectral information, it is important to recognize that digital cameras have significantly different spectral sensitivities relative to the human visual system, as shown for example in Figure 8. However, the spectral sensitivity differences are less important for the UAS system, since image reproduction is not its objective.

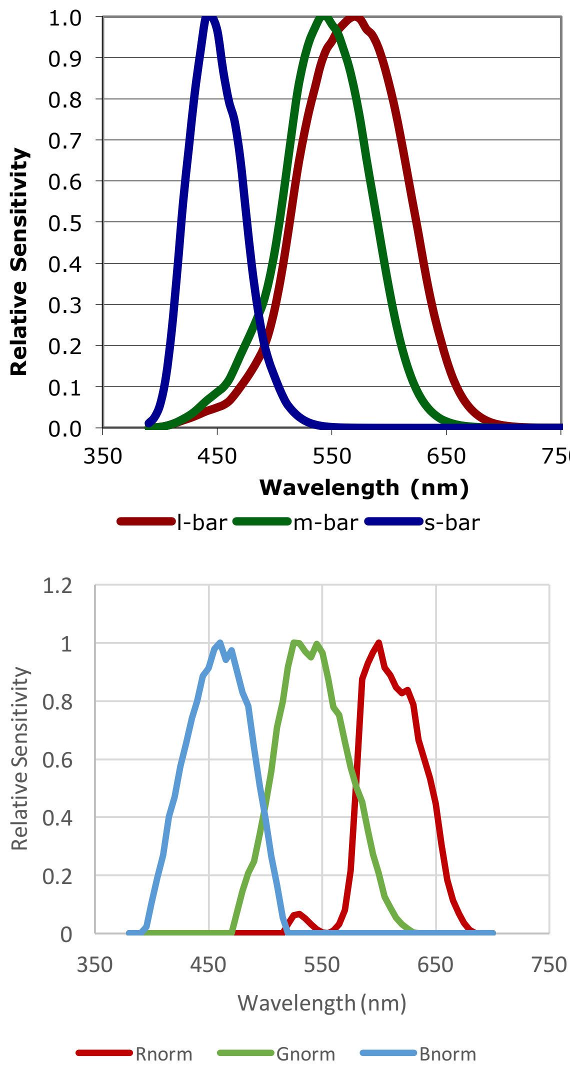


*Figure 8. Top: the CIE 2006 long, medium, and short cone fundamentals (color matching functions); Bottom: camera sensitivities for a Nikon D2x. Note the differences in mid and long wavelength sensor spacing for the photoreceptors relative to the camera sensors.*

## Questions to be addressed

This project is in its nascent stages. We will employ the framework from ISO-17321-1 to guide this effort. However, the differences between still cameras and airborne systems are substantial, requiring additional research for the development of a standard applicable to UAS's. In completing this work there are several important questions to answer. First, in the development of a calibration test target, the patch size required for a usable target is on the order of 4'x4'. At this size, the number of patches that can be included must be minimized. Will it be effective to use a very limited number of patches? What colors are absolutely necessary for this calibration procedure to provide meaningful color values? Along with identification of the needed color patches, other aspects of the calibration test target must be addressed. What materials should be used in its construction? Requirements for spectral response in the range from ultraviolet to infrared, color stability including light-fastness, minimal specular reflection, negligible fluorescence, portability, availability, and rigidity must be considered in making the material selection. The impact of surface texture on target function will also be explored. Does added texture improve or have a deleterious effect on the performance of the calibration procedure?

In addition to the questions surrounding calibration target construction, questions regarding the use of the targets must be addressed. Chief among these concerns is determining how often the target need to be imaged. To answer this question, an understanding the degree of measurement variability under the expected range of capture conditions must be developed. Using this information, the number of image captures needed can be established. If the UAS includes an onboard luminance level sensor, information regarding significant ambient light level changes from this device may be used in the determination of the calibration capture strategy integrated into a given flight plan. What 'significant' means is another question to be answered by the research being conducted for the proposed standard.

## Future work

In addition to the efforts on colour calibration, there are other image characteristics that could be the aim of industry standards for UAS's. These include noise and dynamic range measurements that may be possible with a large version of the ISO 15739 target and resolution using the slanted edge methodology. Geometric distortion measurements would also be valuable but may be difficult measure from 400 feet. While all of these questions are important and interesting, they will not be included in this proposed project.

## Conclusion

Unmanned aerial systems are being deployed in a wide range of applications, such as agriculture, infrastructure inspection, environmental evaluation, and cultural heritage research. Maximizing the efficacy of these systems in the varied applications will likely require the use of targets composed of patches that adequately represent the spectral content of the materials being imaged. The objective of this project is to develop standards for such application-specific color targets, along with the necessary code and a qualitative methodology for using them to calibrate UAS cameras. To successfully develop this new industry standard will require answering questions regarding test target architecture and implementation. Those interested in participating in this work should contact one of the authors, or the IS&T standards administrator at standards@imaging.org.

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## Author Biography

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