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What Does a Drone See? How Aerial Data Resolution Impacts Data Protection.

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Abstract

The introduction of General Data Protection Regulation (GDPR) means that organisations are responsible for data protection for all individuals within the E.U. One area of operation that is unclear is to what degree aerial camera systems capture personal data. Mega-pixels and ground sampling distance are normally used as metrics for camera resolution but they ignore a multitude of factors and do not reflect the actual resolving power of the camera system. This work examines the resolution gap by detailing what is actually captured in the image output and how this can be used as an objective measure when addressing privacy concerns. A methodology is described for easily benchmarking the output for different camera systems at different heights and then two of the most commonly used capture systems on modern drones are evaluated. Finally, we examine how this can be applied to GDPR policy and how aerial surveys can be constructed that remove any personal data from the dataset.

1 Introduction

The motivation for this work originated from a planned aerial site survey using a drone. Although previous surveys had been carried out under the existing Irish guidelines, the intention was to organise a survey that conformed with the GDPR legislation. One of main issues that came out of this process was that there was no clear studies of image quality and how much personal information was captured. Was it possible to carry out a survey without capturing any personal information and if so, at what distance?

In order to answer this question the image data captured by the drone needs to be analysed. Although there are several previous works addressing drone accuracy and resolution [Kung et al., 2011, Draeyer and Strecha, 2014, Kedzierski and Wierzbicki, 2015, Meißner et al., 2017], they focused on ground sampling distance, 3D reconstruction accuracy and radiometric qualities of the image data. There are also studies using face detection at low altitudes [Hsu and Chen, 2015] and work comparing blurring effects on imagery for quantifying privacy [Nawaz et al., 2017] but the aim of this study is to record the resolution as captured by the drone and objectively measure it. This work focuses on the features captured under near-ideal conditions and recording the maximum level of detail that can be captured by the system.

Additionally the resolution of the data is going to depend on the camera system being used. A study judging the resolution of one drone will not be applicable to another that is using a different camera system. We address this research gap with a low cost test that allows for the resolving power to be recorded on any aerial camera system. It is used to measure the resolution on the two most commonly used drones [Van Hoy and Wang, 2016], The Phantom 3 professional (P3P) and the Phantom 4 Professional (P4P). The P3P is fitted with a consumer grade camera and a 1 / 2.3 image sensor comparable to that found in most phones and point and shoot cameras. The P4P has a higher quality camera system with a 1 inch image sensor found in better quality camera systems, such as DSLRs. We examine the results of images captured at different heights and finish by discussing how the results relate to the personal information captured.

The paper is organised as follows: Section 2 outlines the factors that affect image quality in a camera system and Section 3 describes metrics for measuring that quality. Section 4 describes the test used for measuring the resolving power for the camera systems. Section 5 describes the experimental settings and environmental conditions for the experiment. Section 6 analyses the results from the experiments and Section 7 discusses the implications of the results and how to address privacy concerns in a survey. Finally Section 8 summarises the work carried out in this paper.

2 Factors Affecting Image Quality

A camera is essentially a passive sensor system. The quality of the image is dependent on the amount of light in the environment and how much of the light is captured by the camera system. The three main components which directly affect this are the optics (lens) which focuses the light, the sensor (CMOS or CCD) which converts the light into electrons and the image processor (Analog to Digital converter and digital signal processor (DSP)) which converts the electrons into numerical colour values.

The environmental factors in conjunction with these three components are what focus the light, record the light and convert it into a digital image. Using this framework (environment, optics, sensor, image processor) we can examine the variables that affect the image quality and at what stages they occur.

Environmental factors consist of the light hitting the camera lens, the movement and temperature of the camera a particles and moisture in the air. The optics would involve the distortion of the light caused by the lens, aperture and shutter. The sensor size will determine how much light is captured and the type of sensor whether CMOS or CCD also effect how the light is read. The dynamic range and sharpness effect the quality of light capture and residual dark current on the sensor will further worsen the quality of the image. Finally image processing steps such as the analog to digital converter, the compression algorithm, the exposure accuracy and resampling techniques used to increase the resolution of the image will further degrade the fine details in the image.

The effects of the environment were not examined in detail in this work, instead each of them were minimised in the experiment. A day was chosen with sufficient ambient light to cleanly capture the image with the lowest ISO settings. The day was overcast so there was a consistent diffused light throughout the scene with a minimal dynamic range. The images were taken directly downwards with a stabilised gimbal to limit camera movement. Additionally the images were all captured in a short time frame so that the environmental variables were consistent across all of the images.

Two different camera systems were used in order to compare the effect of using different optics and sensors. Although it is difficult to distinguish what parts of the system are affecting the quality the biggest difference between the two camera systems is the sensor size.

This work will initially analyze raw data in order to understand the effects that are caused by image processing. We will then conduct a comparison of the RAW data against the JPG version of the image in order to measure the effect the image processing has on the quality of the image.

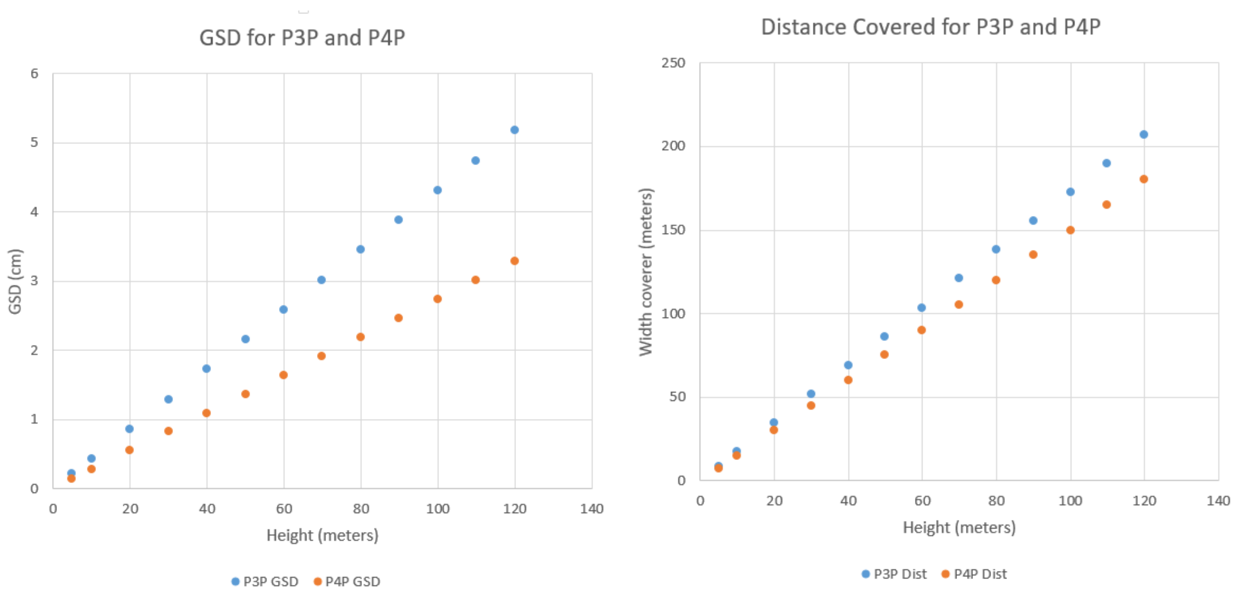
3 Measuring Image Quality

The most common measurement technique is to count the number of pixels in the output image and use this to approximate the image quality. The problem is that this figure can be manipulated during digital signal processing to generate higher pixel counts. For example, a small sensor accurately records colour values across a 640 by 480 array. The DSP can use interpolation techniques to approximate what the pixel values might be between these existing pixels thus allowing it double the resolution and quadruple the pixel count of the camera. Of course there is a trade off to such approaches. The interpolation is just an average approximation and reduces the sharpness of the image, removing clear edge boundaries and decreasing contrast, features that are hugely important for image processing and computer vision.

The Ground Sampling Distance (GSD) is a pixel based metric commonly used in remote sensing for defining the resolution of an image. It computes the distance between pixels in an image as measured on the ground. An image with 10cm GSD means that the centers of adjacent pixels are 10 cm apart on the ground.The formula for calculating the Ground Sampling Distance is as follows:

$$GSD = \frac{FlightHeight * SensorWidth}{FocalLength * ImageWidth}$$

This is easily computed given these input values and is shown in Figure 1 for the P3P and P4P. This is useful as it provides an upper bound on the image resolution (the sampling limit of the pixels). The equation can also be used to approximate the area covered for a given height, as shown in Figure 1. Unfortunately it gives no real indication of the resolution due to the simplicity of the model. It is based on output pixels which can be up-sampled, compressed and manipulated and it ignores all of the factors described in Section 2.



(a) GSD (b) Distance captured

Figure 1: A comparison of the GSD and distance captured between the P3P and P4P

Flattening all the information recorded by a camera into a single numerical value will never allow for an accurate objective measure of the resolution of an image. Instead, an objective measure of feature resolution is required in order to judge the resolving power of aerial camera systems. This work uses a calibrated target that records an accurate sample of what is captured which is discussed in the next section.

4 Resolution Testing

Image resolution tests help assess a camera's ability to resolve detail. Resolution tools were in use even before the invention of cameras for applications such as astronomy and microscopy. One commonly used resolution test is the Ronchi test [Ronchi, 1923]. Although a grating was used for astronomical tests, the Ronchi lines has been incorporated into many standard tests, such as the 1951 USAF resolution test chart. The spacing between the high contrast lines allow us to examine the modulation transfer function that defines who well the contrast in the original object is maintained by the detector.

The chart described in this work, shown in Figure 4 uses sets of Ronchi rulings to calculated resolution power and borrows heavily from the USAF standard chart. The primary difference is that the images are laid out so that they can be easily printed on a standard printer to create the target. Images were also added in order to test two common GDPR metrics, namely facial features and a license plate.

5 Equipment and Experiment

The two drones used in this experiment are the Phantom 3 professional and the phantom 4 professional. These provide a useful comparison as they have two very different camera systems that are found in many standard and high end drone camera systems. They vary regarding the optics, shutter type, the sensor size and the mega-pixel output. They DJI Phantom series is one of the most popular and recognizable drones on the market.

The Phantom 3 professional uses a 12 mega-pixel Sony Exmor 1/2.3 inch camera system (IMX377) with a fixed aperture and electronic shutter. The system has a diagonal 7.81 mm (Type 1/2.3) CMOS image sensor with a colour square pixel array and approximately 12.35 M effective pixels. It uses an electronic shutter function with a variable storage time. The 20mm wide angle lens (F-Stop 2.8) has a field of view of 94 degrees. It is commonly found in consumer electronic products and is used also in the Phantom 4 standard, the Inspire X3 and the GoPro Hero 4/5.

The Phantom 4 professional uses a much larger Sony Exmor R IMX183 1 inch sensor system that outputs a 20 mega-pixel image. It is backlit to improve light sensitivity and reduce noise. The wide angle lens has a variable aperture, (F-Stop 2.8 to 11) and an 84 Degree field of view. The sensor is used in high end camera products such as Sony's RX100, DSLRs, and astronomical telescopes.

The predominant difference between both camera systems is the sensor size, which is highlighted in Figure 2. The IMX183 sensor has 4 times the surface area of the IMG377 sensor. The experiment will examine what difference this makes, if any, in the RAW output.

Figure 2: The size difference between the two sensors, the 1 inch sensor has 4 times as much surface area.

5.1 Experimental Settings and Environmental Conditions

The day chosen for carrying out the test was a slightly overcast yet bright day. There was no direct sunlight and instead a diffused ambient light, resulting in a illuminated with limited shadowing. A light meter was used to record the ambient light value. The values varying between 7200 and 8000 Lux (Lumens per meter) were recorded. For comparison an overcast day is 1000 Lux, full daylight without direct sun is 10,000 Lux and direct sunlight is 32,000 to 100,000 Lux. The experiments were carried out in quick succession and the RAW and JPG images were recorded simultaneously in order to minimise the amount of variation during the experiment. The camera settings were recorded before and during the flight and are shown in Table 5.

Setting	P3P	P4P
ISO	200	100
Shutter Speed	cell8	cell9
F-Step	2.8 (Fixed)	4
EV	0	0
Exposure	Auto	6100K @ 5m 5400K @ 90m

Table 1: Camera settings for the experiment

The target consists of several sets of Ronchi Rules designed to fit on standard A4 paper, as shown in Figure 4. The smallest set is 10mm horizontal and vertical lines in the top right of the target. The Ronchi rules on the two pages following show line thicknesses at 20mm and 40mm respective. The two pages at the bottom of the target show lines 60mm thick horizontally and vertically. The top left shows a checker board pattern at 40mm resolution and the text in the main target (EPL) is 144 mm high. Two additional targets were created. One showing a standard Irish license plate with text the regulation size (60mm high) and two cartoon faces the approximate length of a standard human face (220mm to 250mm). The author also included themselves as a target aligned directly with the camera, this is to provide a comparison with the other data to verify if features remain visible at height. The subject's permission was obtained to use their personal information in this work. The target is publicly available for download at: `https://www.scribd.com/document/382177071/Downloadable-GDPR-target` and is licensed under the CC-BY 4.0 License.

6 Experimental Results

The RAW image results for both the P3P and P4P at different heights are shown below. Like a negative from film photography, the RAW data is not directly usable as an image, but contains all of the information needed to create an image. It allows for the adjustment of colour balance, dynamic range and luminance and is not affected by artefacts that result from image compression. The images were processed using Adobe lightroom in order to choose the brightness, contrast and exposure that best highlighted the text and patterns on the target. The adjustment that generated the best improvement in clarity was decreasing the luminance. The highlights were decreased to minus 80 and the shadows to between minus 60 and minus 80.

Figure 3 shows the results obtained from the aerial images, the minimum resolution considered are the minimum visible Ronchi rulings, even if the lines are aliased or missing less than 50% from white out. It shows the GSD is a poor metric for minimum resolution. It almost doubles the minimum resolution when compared actual minimum resolution. Due to space limitations the results can be viewed online at:RAW results P3P, RAW results P4P, JPG results P3P and JPG results P4P.

7 Discussion

The results in the previous section clearly show that the theoretical resolution does not match what is actually captured. For example the GSD of the P4P at 20 meters should be 0.54 cm but it is difficult to resolve anything less than 2 cm. Several confounding factors, such as brightness, optics and sensor size are affecting the quality and shows the GSD a has little bearing on reality.

The sensor size is also shown to greatly effect the quality of the image. The P3P and P4P clearly have different performance for the same environmental conditions. No distinguishing features can be

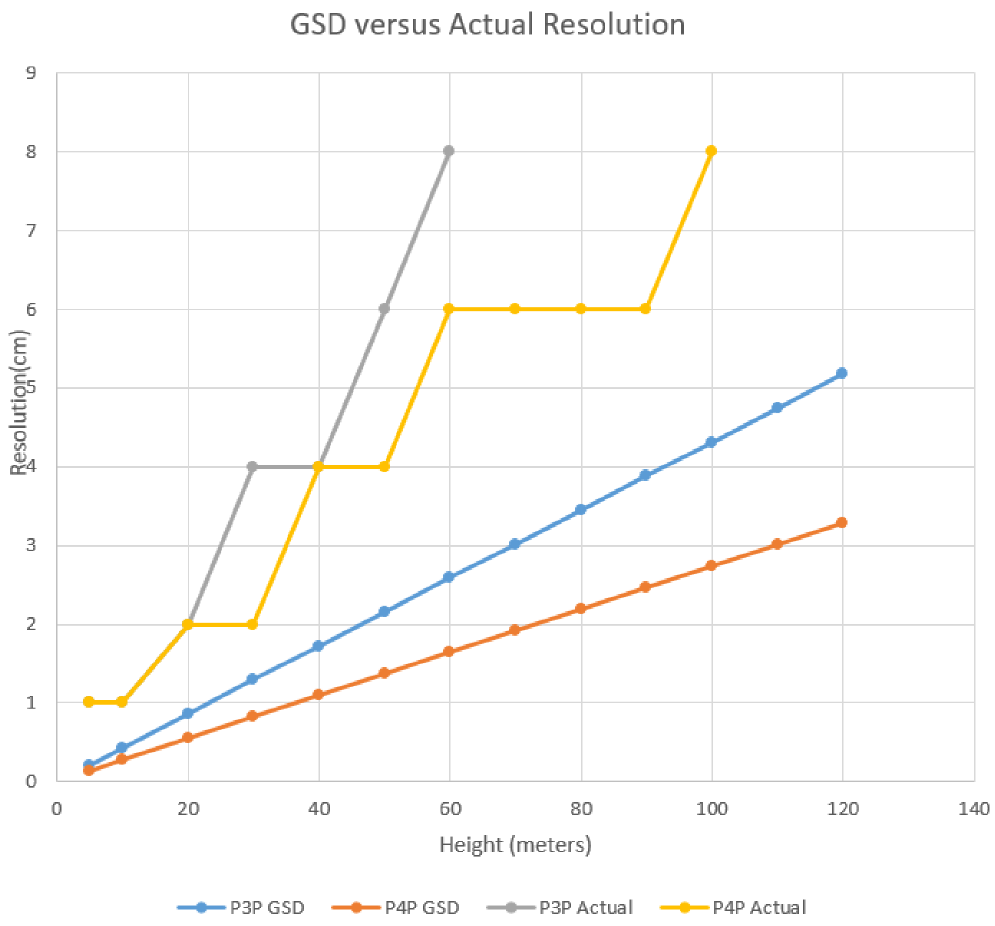


Figure 3: A comparison of the GSD versus the actual resolution visible in the Ronchi Rulings.

seen in the P3P image at a height of 30 meters whereas the same can only be said of the P4P at 50 meters.

The post-processing of the image further worsens the problem. JPG compression and reduces the resolution of the image even further and sets brightness levels that best suit the whole image but overexpose fine grained details. The result is that features that are clearly visible in the P4P raw image at 30 meters are blurred beyond the point of recognition.

7.1 Ramifications for GDPR

The result of this study shows that it is possible to conduct a survey without capturing personal data and so mitigate the risk of the survey processing personal data.

minimize the privacy risk to individual while mitigate these risks and so it is not processing personal data . The following conclusions can be drawn from the results:

- GSD is a poor metric for privacy concerns. Too many factors are at play and each camera system will have to be calibrated against a target to ensure privacy by design.
- Surveys conducted at a minimum height of 30 meters by the Phantom 3 or 50 meters for the Phantom 4 will not capture personal information. The focal resolution of the camera is such that license plates or the faces of individuals will not be identifiable.
- Post-processing, such as JPG compression, will further reduce the quality of the images. While

this decreases the amount of personal information captured, there should still be a margin of error as the quality of compression can vary.

- Regardless of whether personal information is captured, notification that a survey is taking place should be provided, either through signage or direct contact. The persons on the ground do not know whether personal information is being captured or not. For transparency they should be allowed to follow up on the survey to confirm their data was not captured.
- Additional manual verification steps should be carried out to ensure no personal data is inadvertently captured. If there is personal information in the data, processes should be in place to redact or erase it.
- Although data verification risks inadvertent temporary processing of personal data prior to erasure, this does not meet the data protection impact assessment threshold in Article 35, which is only triggered where there is a "high risk" to the rights and freedoms of natural persons.

As such, a robust design of survey and careful control of the images (verification, storage, encryption) can allow for it to be conducted with a minimal risk of capturing personal data and for removal of any personal data before the survey is processed.

8 Conclusions

In this work a methodology for objectively measuring ground resolution was put forth. The resolution of two camera systems, the Phantom 3 professional and the Phantom 4 professional, were then tested. It was shown that the ground sampling distance bore little relation to the actual resolution of the data captured, with no personal information being visible at a height of 30 meters with the Phantom 3 and at 50 meters with the Phantom 4. It was further shown that the image sensor size massively affects the quality of the result and JPG compression further degrades the data.

The work shows that it is possible to carry out with a simple test in order to verify the functional resolution of a camera system. Computing the resolution allows for privacy by design to be implemented in the survey. Minimal personal information is captured and with proper validation steps, that a survey can be done in such a way to contain no personal information. This enables privacy by design, and complete anonymization of the survey data.

9 Future Work

The environmental variable were not explored in this work, instead ideal ambient light conditions were chosen. In future the effect of different lighting and atmospheric conditions will be explored. We intend to test different camera systems against the resolution chart and generating an online gallery of images for different systems to be used as a reference of camera resolutions.

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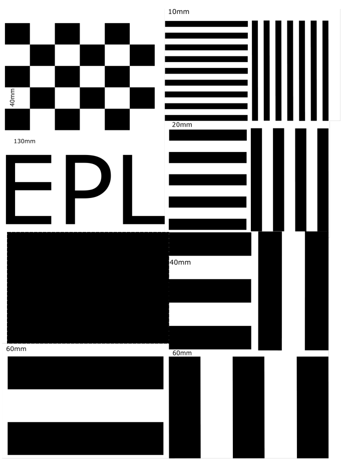
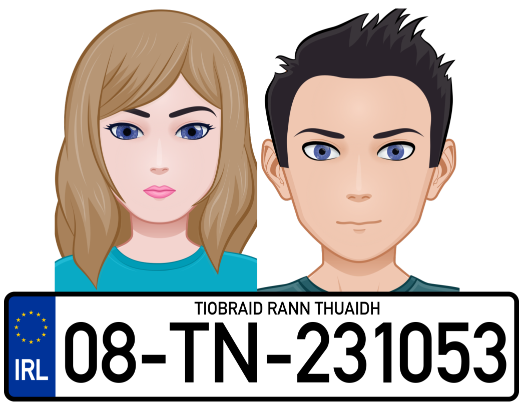
A Results Appendix



(a) Resolution Test



(b) GDPR Test

Figure 4: The layout of the Ronchi Rulings to test the camera resolution and feature recognition.