

THE SURVEY ASSOCIATION

# CLIENT GUIDE TO **PHOTOGRAMMETRY**

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Endorsed by:
RICS chartered ices

The Survey Association's Client Guides are primarily aimed at fellow professionals such as engineers, architects and planners. They are not intended to be an 'in depth' source but to act as a basic guide on a specific topic and, in particular, on procedures which may govern how a certain aspect of a survey is carried out.

## Executive Summary

The purpose of this guide to photogrammetry is to provide a framework for the practice of photogrammetry for the client commissioner. It covers theory, practical examples and a wide range of applications for which photogrammetry can be used. Recent advances in the technology have brought the discipline up to date with higher resolution cameras, unmanned aircraft, and faster and more autonomous processing for managing large volumes of data.

Figure 1
DJI Phantom SUA wide angle image

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## 1. Photogrammetry – Introduction and Definition

This document is a general guide to photogrammetry with a greater focus on terrestrial and small unmanned aircraft (SUA) surveying. TSA has published additional Client Guides covering the subjects of standard aerial photography and aerial orthophotography.

Photogrammetry can be defined as the art, science and technology of determining the size, shape and identification of objects by analysing terrestrial or aerial imagery. It has existed since the nineteenth century soon after the invention of photography. The first developments tended to concentrate on its use in architectural surveying. From the early part of the twentieth century the focus was on aerial survey, inspired by the need to produce faster and better quality mapping for military purposes, national coverage and large scale survey for infrastructure. The rapid and remote data collection techniques were seen as the prime advantages.

Instrumentation, in the form of large format cameras and processing equipment, also developed rapidly through the latter half of the twentieth century. The mapping equipment progressed from purely optical/mechanical instruments, designed to reproduce the position and orientation of the images, through computer-aided machines and, ultimately, to digital workstations. The latter have no specialised adaptation from powerful desktop computers, other than having a stereo viewing capability and a more sophisticated mouse.

The latest developments have seen the rapid progress of more fully automated user-friendly software at a lower cost, making itself accessible to a wider number of customers including the end users of the products. The impetus for change is due to the incorporation of computer vision algorithms and improved workflows, the relative affordability of good quality cameras, computers and storage media and the increased use of SUA, capable of carrying lightweight cameras. The software may be known as SfM (Structure from Motion), convergent or multi-photo systems.

## 2. Scope of the Document

The basis for photogrammetry relies on the fact that any object photographed from different locations will be reproduced in different positions in each image plane. If the positions of the camera and its internal geometry are known, the location of the object in the real world can be re-constructed. This is not a straightforward exercise as the cameras can be tilted and the lenses may suffer from a number of distortions. The basic principles of photogrammetry will be explained in Section 3.

The distribution and quality of the imagery also has a primary bearing on the outcomes and an explanation of some camera settings and photographic requirements will be covered in Section 4.

Processing on digital workstations is through dedicated software, with input from the operator limited to identification and observation of control points, and the setting of various parameters in line with the requirements of the project. End products can be produced automatically or semi-automatically and consist of dense point clouds (similar to laser point clouds), triangular meshes, image rendered surfaces (3D models) and orthophotography (image maps). These data processing stages will be considered in Section 5.

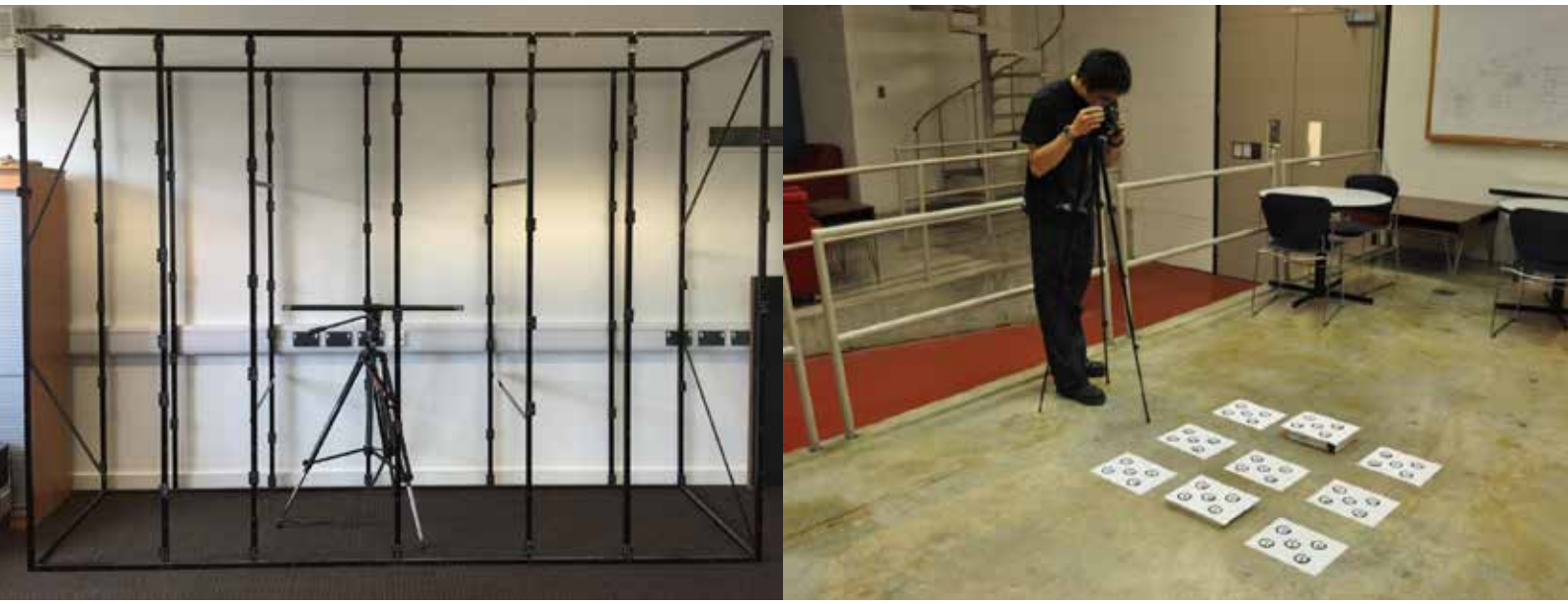


Figure 2
Permanent calibration frame set up at The University of Nottingham (left) and A4 sheets of coded targets for Photomodeler Scanner software (right)

However, vectorisation (feature collection) remains a largely manual process, using the knowledge and experience of the photogrammetric operator to accurately and efficiently identify and plot the features relevant to the project. For example, this can be the production of housing and roads for a large scale topographic map or the collection of architectural features for a building survey. Mapping will be looked at briefly in Section 6.

## 3. Basic Principles and Procedures of Photogrammetry

Photogrammetry depends on knowing the path of the light rays from the object to the image sensor and this process can be described by three largely separate elements that work to achieve a geo-referenced set of imagery. They have been traditionally known by the terms inner, relative and exterior orientation.

**Inner orientation** is the procedure that determines the interior geometry of the camera by calibration. The calibration can be computed automatically within the photogrammetric software and the relevant parameters, in some systems, can even be calculated individually for all photographs. This allows for greater flexibility in the camera settings and lenses used on any one project. For higher precision work

calibration is conducted as a dedicated exercise by photographing a calibration field of known targets and comparing their image positions with the true coordinates. See Figure 2. The calibration calculates the focal length of the lens, any offset between the centres of the sensor and the lens and the distortions inherent in the lens. The main distortion is a radial effect, giving the image a barrel or pin-cushion appearance. It is common in many wide angle lenses and the SUA image in Figure 1 is a good example. Once the camera geometry is determined each ray of light from the object can be adjusted to its (idealised) position in the image space – the position in a perfect camera. This is an essential first process for the precise reconstruction of the 3D model space.

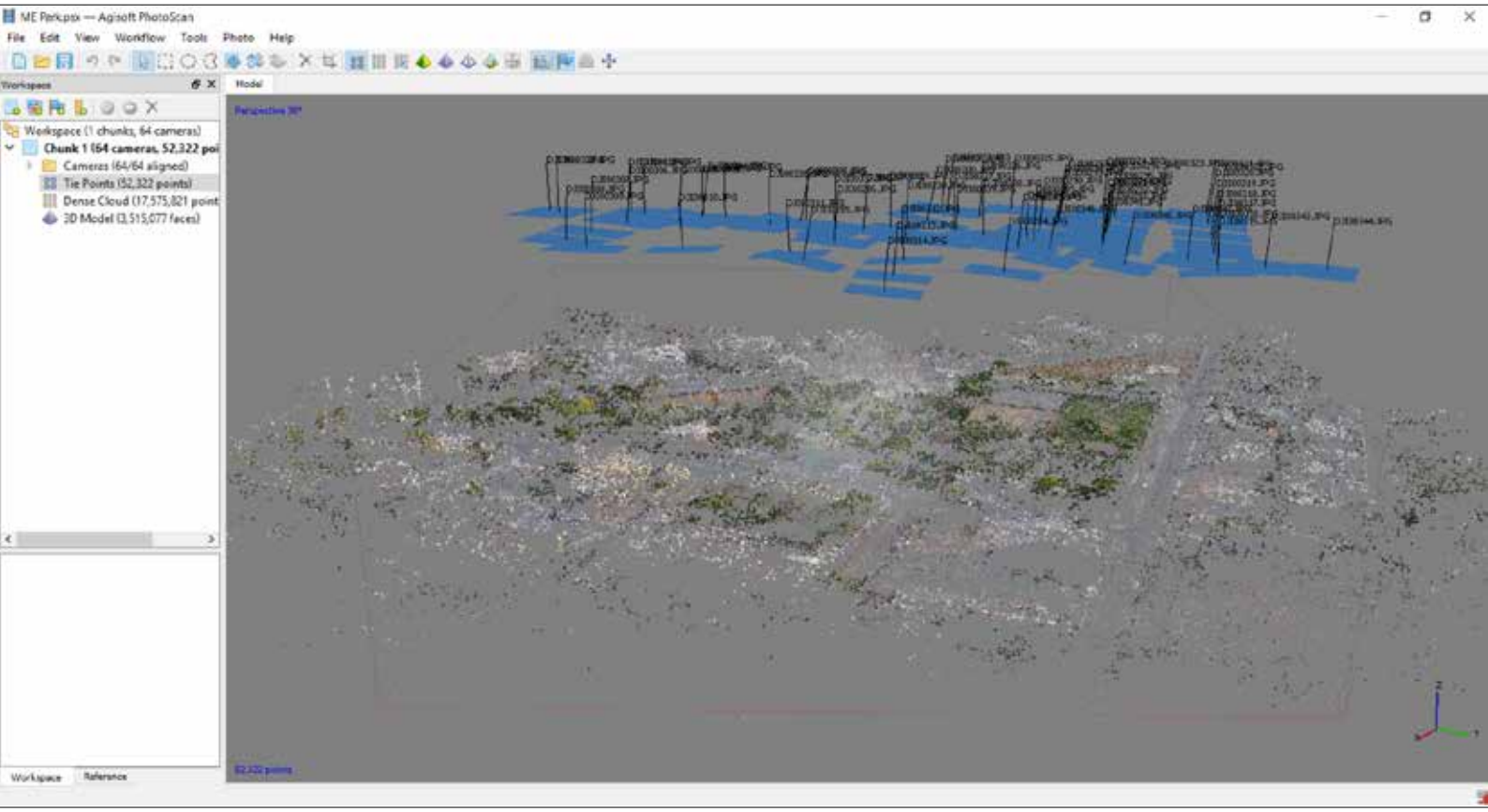



Figure 3
The relative orientation/ triangulation process has produced 52,000 tie points effectively forming a sparse point cloud. The distribution of the SUA imagery is also shown. Software: Agisoft Photoscan

Relative orientation is the procedure to determine the relative positioning of all the overlapping photographs in the project. Every image will have some degree of difference in scale, orientation and location when compared to others in the dataset. This is generally minimised in dedicated aerial cameras by using GNSS, inertial measurement units (IMUs) and gyro-stabilisation. However, a wide variation in orientation can be a positive advantage in terrestrial and SUA photography where the data is to be processed by the modern multi-photo software algorithms.

The relative orientation is achieved by automatically matching features in overlapping photographs. The variation in size and shape of the common areas provides the data to manipulate the scale and orientation of the images in a block. This process is also known as removing the parallax between images – parallax being the measure of the difference in position of the same point in matched images.

The exercise produces an overall fit with a few thousand tie points very quickly. This relative orientation of many images simultaneously is also called aerial triangulation or bundle adjustment. These terms are derived from the older pair by pair procedures and subsequent rigorous mathematical adjustments of traditional stereo photogrammetry. When viewed, the triangulation tie point dataset forms a coarse 3D model of the object or topography and is sometimes known as the sparse point cloud. See Figure 3.

**Absolute orientation** is the process of geo-referencing this arbitrarily scaled and orientated model into a recognised local or national coordinate system. Imaged points of detail or targets are observed in the model system and transformed (scaled, orientated and translated) to the ground system. These would normally have been coordinated by land survey methods using theodolite total stations or GNSS. Control point observation is generally a manual process but if coded targets are used some systems can recognise them and perform the transformation fully automatically. If the camera has on-board GNSS and IMU systems the amount of control, even in a large block, can be as few as a handful of points. If the adjustment stage (relative orientation) produces very accurate results only a few points may be required, even for terrestrial projects. However, this will depend on a good distribution of imagery with a great deal of overlap at varying angles.

## 4. Photography

As the quality of the photography has a critical bearing on the final product, a brief guide follows. It is a general rule that the higher the quality of the camera/lens combination the better will be the resulting output. This is largely due to the pixels being larger in larger format cameras (digital SLRs, medium format cameras and dedicated aerial cameras) than in compact and phone cameras. The greater the area that can accept light the more accurate will be the rendition of colour and tone and less noise will be generated in low light conditions. See an example of the range of cameras available in Figure 4.

Figure 4
An example of the range of cameras available for photogrammetry from left to right: Airbus Pleiades 50cm GSD satellite system, Leica DMCIII 390 megapixel aerial camera, Canon 5DS 50 megapixel DSLR and Samsung Galaxy S6 smartphone with 16 megapixel camera




Cameras are familiar objects. We take their point and shoot ability for granted and expect to take a perfect shot every time. However, for photogrammetric purposes there are a number of factors to consider.

### 4.1 Camera settings

It is important to know how to use the camera settings to maximise the quality of the imagery.

#### Focus

For feature extraction, automatic image matching and for the production of any image-based products, such as orthophotography, it is essential that the area of interest is sharply focussed. This is usually straightforward for aerial imagery where the distances are greater but for terrestrial subjects there may be significant depth. This is usually solved by using a smaller aperture which automatically increases the depth of field.

#### Illumination

It is also important to have enough light available and by closing down the aperture, as in the example above, less light will enter the lens. This can be solved by artificial illumination, such as on-board flash, but this is not always appropriate or powerful enough. For the higher quality cameras the ISO setting can be increased which

effectively improves the sensitivity of the pixel array. This may be at the cost of increased noise in the image but significant advances have been made in this area for high end DSLRs. Variation in the angle of illumination for any off-camera lighting can enhance the relief and assist in the interpretation of the subject. An example is shown in Figure 5. This imagery was taken of Mayan hieroglyphs as part of a photographic protocol for the monitoring of erosion.



Figure 5
Variation in illumination to enhance relief. Lighting angles (left to right): side 45°, side 80°, top 45° and top 70°

### Exposure compensation

If a dark subject is set against a light background or vice versa the exposure normally has to be increased or decreased respectively. This can easily be done by spot monitoring the exposure or by adjusting the Exposure Values (EV) on the camera to override the automatic monitoring.

### Storage

It is important to ensure that the highest quality images are stored on the camera and if the camera has a Raw setting this should be used. This setting retains the original image and is not subject to any compression artefacts that may occur when storing the image in the JPEG format. Although image enhancement is not recommended, as the automatic matching procedures can be affected, the Raw format allows better adjustment of brightness, contrast, exposure and white balance.

## 4.2 Lenses

Prime lenses are normally recommended in preference to zoom lenses due to the superior quality of manufacture and the reduced number of moving parts. The lack of robustness of zooms can mean that the focus setting used in the calibration may slip unknowingly and potentially affect the accuracy of the calculations.

Wide angle lenses produce better coverage and the better conditioned internal geometry improves the mathematical solution. The narrow cone of light entering a telephoto lens significantly affects the accuracy. Very wide angle and fisheye lenses should also be avoided due to the severe distortions which cannot always be mapped accurately, especially near the edges of the frame.

## 4.3 Distribution of the imagery

The distribution or arrangement of the imagery was mentioned earlier in the context of improving the geometry of the solution for multi-photo systems.

The distribution for **standard stereo mapping** is different and it is important that successive images in a run of photography maintain a near parallel axis. This is the normal case for standard aerial photography as the camera is pointing vertically downwards but should also be considered for terrestrial imagery when digital stereo workstations are to be employed for feature collection. The stereo software is designed for this case and, as the operator spends a great deal of time collecting data, it is important that the viewing resembles that of a pair of eyes for comfort. Feature collection on multi-photo systems is less common and in all cases the process takes place observing the 3D model or one image at a time. The standard stereo case for aerial and terrestrial imagery is shown in Figure 6.

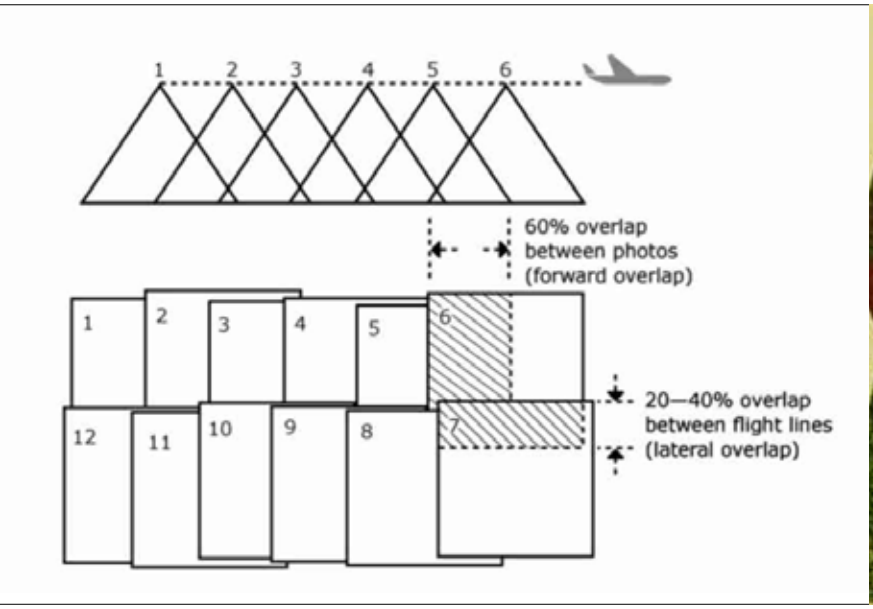
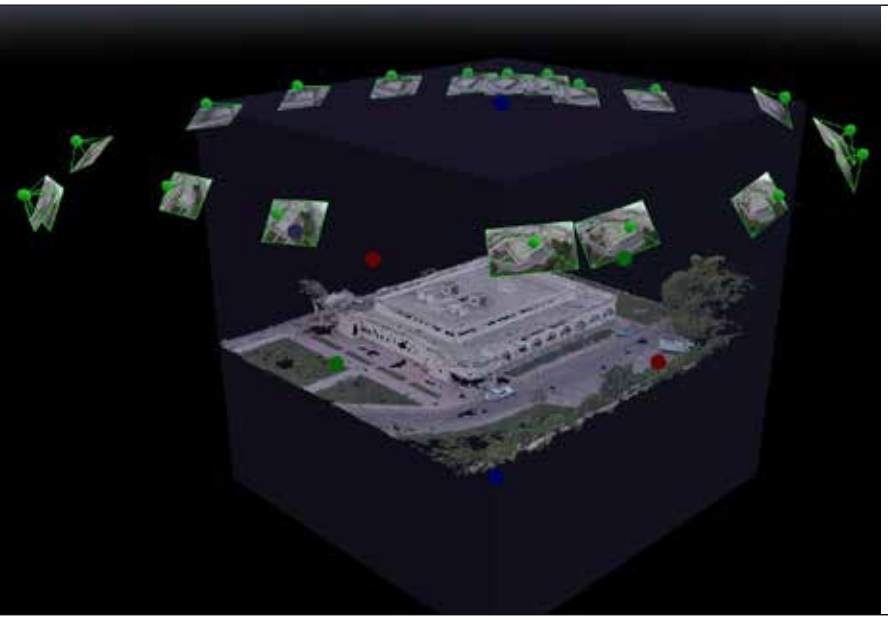





Figure 6
The standard image arrangement (parallel camera axes) for aerial (left) and terrestrial (right) stereo photography

The arrangement for **multi-photo methods** can be more random and the important considerations are for significant overlap across several images and variable angles of view for improved geometry and coverage. The latter is especially important if a 3D model is to be produced as blank areas (no coverage) detract from the final product. Examples of the distribution of imagery for multi-photo methods are given in Figure 7. When a rotary SUA is used all options are available for regular flight lines, circular, oblique and horizontal imagery.



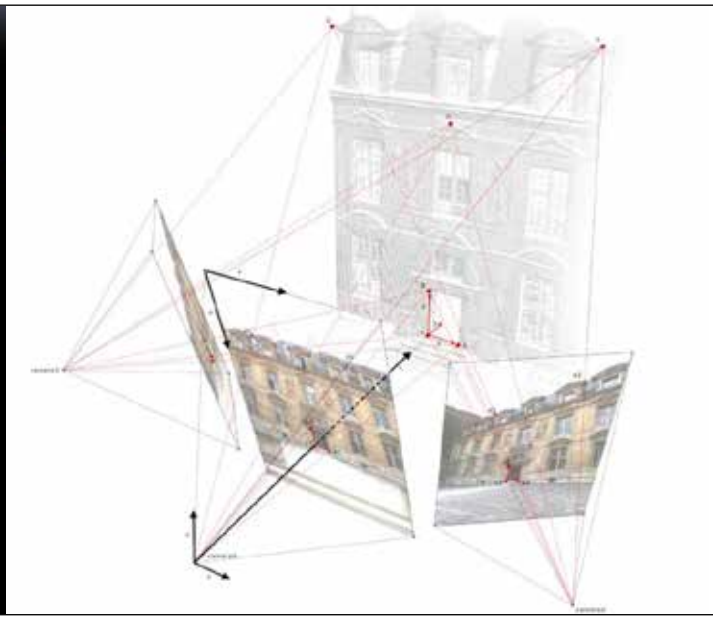


Figure 7
The distribution of photography for multi-photo methods. On the left a rotary SUA has taken a circular set of obliques of a large building to cover both the roof and the elevations. On the right an elevation is photographed from three angled positions (De Luca, Veron and Florenzano 2006)

## 5. Data Processing and Photogrammetric Products

### 5.1 Stereo photogrammetry

If the object of a survey is to produce detailed digital drawings of an urban area, a listed building, an archaeological excavation or an iron bridge, the project should specify a conventional stereo photographic survey.

The vectorisation of intricate three dimensional features only tends to be efficient using this method. There is some automation in the extraction of data from point clouds, for example, in the analysis of the pipework, joints and valves in a chemical processing plant. However, these consist of repetitive features based on the manufacturers' templates or, at worst, scalable primitives such as cylinders or cones. The irregular nature of the façade of a mediaeval cathedral or a city centre cannot easily be pigeonholed. This usually means that a specialist company is contracted to conduct the work in preference to using an in-house multi-photo system.

Established photogrammetric organisations with aerial cameras, digital stereo workstations and experienced staff are sought for large topographic contracts, such as the revision of large scale Ordnance Survey mapping. Byproducts of these contracts such as orthophotomosaics can also be produced at the same time.

## 5.2 Multi-photo methods

If the project is on a much smaller scale or the deliverables consist mainly of automated or semi-automated products, the employment of multi-photo methods using terrestrial or SUA imagery can become more efficient and, as the client is normally more closely involved, controllable.

It was seen at the relative orientation stage above that a coarse model of the object was produced when viewed in 3D using the newer multi-photo systems. The number of points created is usually in the order of 10,000 to 100,000. After it has been geo-referenced (absolute orientation stage), the data acts as a seed to produce the dense point cloud familiar to users of laser scanners. There are a number of parameters that can be set to provide control over the resolution and quality of the point cloud and the area of interest. These combine to optimise the dense point cloud production of many millions of points which can take several hours of computer processing.

Figure 8
3D model construction from 64 SUA images using ContextCapture



Figure 9
A triangular mesh and shaded surface of a vaulted arch using ContextCapture

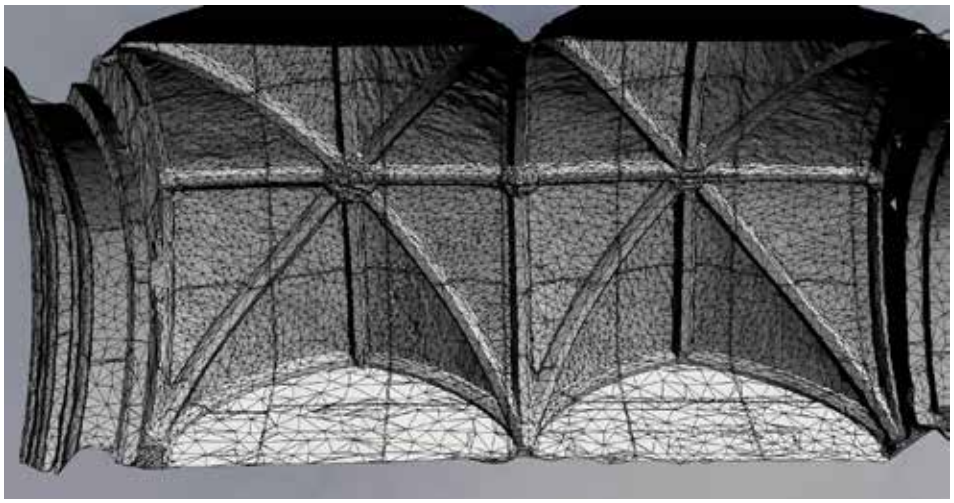


Figure 10
3D textured model of the same vaulted arch using ContextCapture



The **dense point cloud** of 18 million points for the dataset of Figure 3 is shown in Figure 8 and was constructed from 64 10megapixel images. It is interesting to note that the elevations of the buildings are quite well rendered considering the imagery was vertical. The reason is that the lens was a wide angle (20mm lens 35mm camera equivalent) and, therefore, recorded the elevations well at the edges of the frame. The phenomenon can be seen in Figure 1. For more complete and detailed coverage of the elevations a set of oblique photos would also be taken.

The dense point cloud is then used to produce a **triangular mesh** of the surface and if the triangle count is unnecessarily high to define the surface it will be decimated, either automatically or under the control of the operator. This helps to reduce the size of the overall dataset. A surface is then created by filling the triangles with a controllable degree of smoothing and is normally shaded to show relief. An example of a triangular mesh is shown in Figure 9. The results of the decimation can be seen where the triangles are larger on the flatter surfaces of the wall.

The final stage in the production of a rendered (textured) model is prepared and the resolution of the rendering can be set to closely resemble the original imagery if required. This will be at the expense of some additional processing time. A textured model is shown in Figure 10.

This model can then be exported for further improvement in dedicated 3D modelling packages, where holes in the mesh through lack of complete coverage can be interpolated or the mesh can be edited where some noise or obstruction has caused a problem.

A photogrammetric product that is offered by most multi-photo software suites is orthophotography. As the textures from individual images have already been balanced and merged during the rendering stage the instructions to the software set the boundary, the plane of projection and the output pixel size at true scale – the ground sampling distance (GSD) in the aerial context. The process corrects the displacements caused by lens distortion, scale, surface relief and camera orientation. Orthophotos have the high visual information content and familiarity of a photograph but contain the geometric qualities of a map and can be used in a multitude of GIS and mapping applications by accurately overlaying the vector data.

If an orthophotograph is the main product careful consideration should be given to the resolution of the original imagery. It is a general rule that if an object of a certain size is to be seen, the resolution of the imagery should be better by a factor of at least two. For example, if a 10mm feature is identified as being the minimum size required then the photography should be taken at a resolution of 5mm or better. This holds reasonably well throughout the scales such that a 20cm feature should be imaged at 10cm resolution or better. The quality and density of the surface generated is also critical to the accuracy of the end product as excessive interpolation will create errors of displacement.

Figure 11
Model and orthophoto of a statue using Photoscan

Figure 11 shows the 3D model of a statue of Mary and Jesus and the orthophoto of the full statue alongside. The workspace indicates that the dense cloud was produced from eight million points and the orthophotograph has a GSD of 0.6mm. This was estimated by the software as the model was not georeferenced.

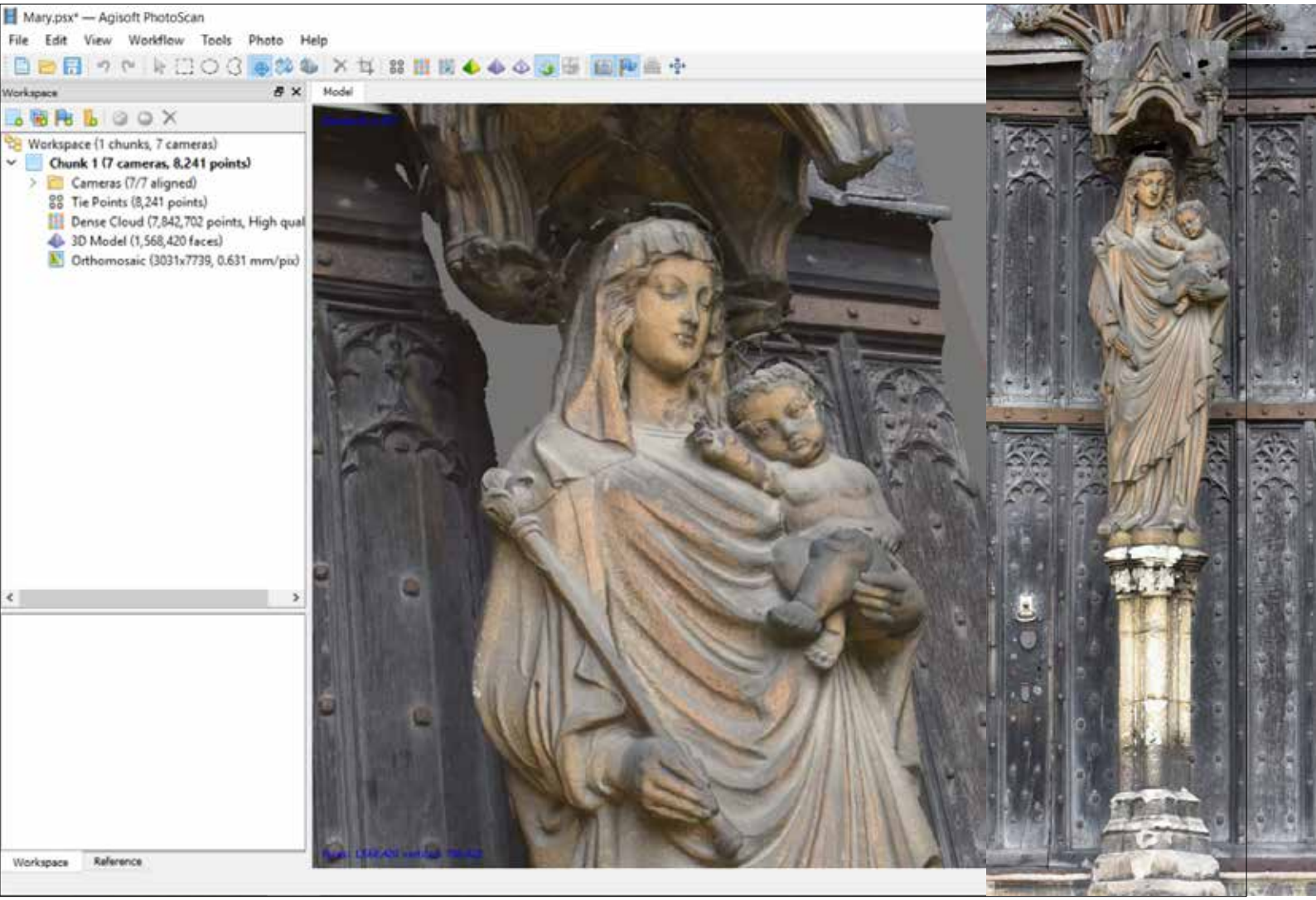



Figure 12 below shows a vector overlay on an orthophotograph of a railway infrastructure project. The vector data was produced in 3D to a precision of 20mm from helicopter photography but the image data displayed which is not normally mapped, such as the sleepers, ballast and cabling, provide valuable additional information to the engineers.

## 6. Mapping and Vectorisation

The newer automated methods do not lend themselves to serious feature collection as there is either no provision within the software or the tools that are supplied are a little basic. As they are useful for small amounts of data they will be described later in this section.

### 6.1 Mapping using stereo photogrammetric workstations

Fully digital stereo workstations have been in common use since the 1990s and Figure 13 shows an example of a twin screen system. Note the stereo glasses worn by the operator and the large 3D mouse. The stereo eyewear is synchronised with the transmitter next to the keyboard so that both the left and right lens open and close alternately, at sixty times per second. This enables the brain to see the data in 3D and is fast enough to avoid flicker.



Figure 12
Part of a high precision data overlay on a 1cm orthophoto of railway sidings at Ashford in Kent

After the orientation process the operator traces the vector data in 3D using the movement of the mouse across the surface to define x (eastings) and y (northings) and the thumb wheel the z (height) coordinate. The data is coded by pressing pre-programmed buttons on the tablet or the mouse to define roads, buildings, trees and other features. All data is in true ground coordinates and is normally superimposed on the image to monitor progress and to easily identify any features not captured.

Figure 14 is an example of a detailed photogrammetric plot of part of the West Front at Lincoln Cathedral. This was produced to the 1:20 English Heritage (now Historic England) standard specification. Stereo photogrammetry is the only practical way to achieve this level of 3D detail.

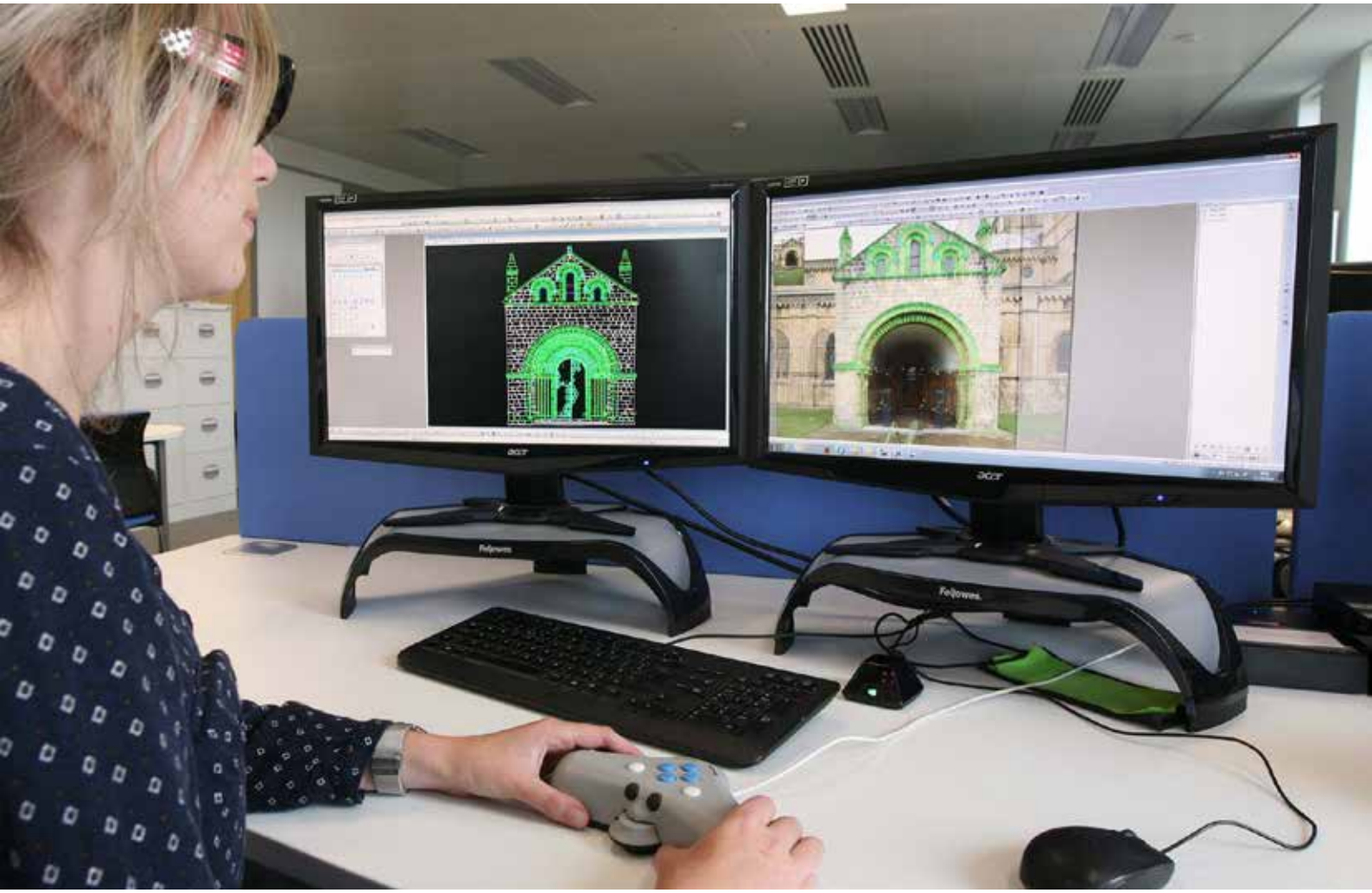


Figure 13
An example of a stereo workstation – DAT/EM Summit

### 6.2 Mapping and vectorisation using multi-photo methods

Mapping can be undertaken using multi-photo software suites but they do not rival full CAD systems. Pix4D allows 3D data collection directly from the 3D model but unless the operator has taken great care to produce a model with the resolution of the original imagery there may be interpretation issues. Photomodeler Scanner has taken a different route by letting the operator digitise the original images in 2D. As each point is collected the surface model is interrogated to provide the third dimension. The surface data collection (which can be layered) only allows points, lines and curves. Export to AutoCAD, for example, requires a little work to produce the finished product. However, for smaller projects both software suites provide a valuable extra facility.

## 7. Advances in SUA photogrammetric solutions

### 7.1 High Accuracy Mapping

Recent technological advances in SUA technology have developed in achieving high precision photogrammetry to an accuracy of within 5mm as shown in Figure 15. The rapid advancement of photogrammetric software has enabled the production of 3D point clouds that match or exceed the accuracy of aerial LiDAR.

Utilising a stable modern SUA platform, a high resolution 100 megapixel camera, low flying heights of between 25m to 40m, a Ground Sample Distance (GSD) of 1-2 mm can be achieved.

High accuracy Ground Control Points are still required to tie the photogrammetry to the survey grid, but the data processing will be a combination of off the shelf processing software and bespoke algorithms to enhance pixel matching.

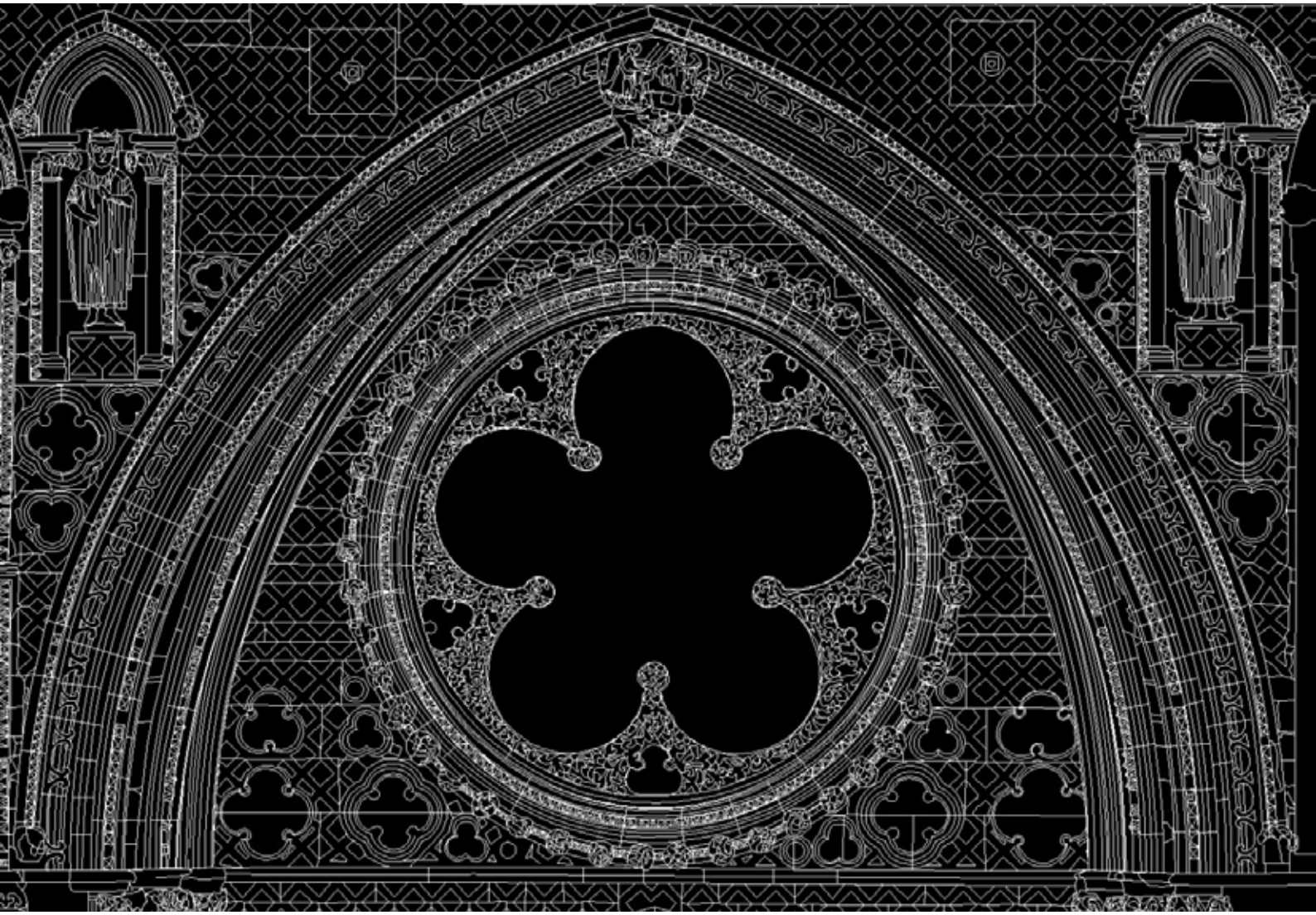


Figure 14
An example of a detailed photogrammetric drawing produced to Historic England standards. West Front, Lincoln Cathedral

As an example, using a stable modern SUA platform, a high resolution 100 megapixel medium format camera and a flying height of 50m, a Ground Sample Distance (GSD) of better than 5mm can be achieved.

The on board GNSS has accurate RTK/PPK units and an IMU that will improve geo-referencing accuracy and reduce the number of ground control points required. For the above example, approximately 5 to 8 GCPs will be required for an area that is in the region of 4 hectares square (200m x 200m) to achieve a theoretical accuracy of approximately 5mm in plan and 20mm in height. As well as perimeter control to contain the area it is important that some points lie within the body of the area to minimise any error propagation along lengthy flight lines. Lowering the flying height generally improves the precision in a linear fashion but the increase in the number of photographs (by a factor of four for halving the height) means that the number of control points will have to be increased significantly. By halving the height of the example to 25m above ground, 15 to 20 GCPs may be required for a similar area to achieve a height accuracy of approximately 10mm.

The above figures are taken from Table 1 and it should be noted that the theoretical accuracies are based on hard and textured surface observations. They are also dependent on image quality, control distribution and control accuracy. The plan accuracy is based on a pointing precision of 1 pixel but may be worse under sub-optimal conditions. The height accuracy is based on the pointing precision and the ratio between camera base (the distance between successive images) and the flying height for 80% forward overlap. This overlap is commonly used for SUA datasets. Automated algorithms and multiple manual observations can improve these height accuracies.

| Camera type | Camera example | Resolution (mp) | Lens (mm) | Flying Height (m) | Images for a 4Ha square 80% fwd o'lap 50% side o'lap | GSD (mm) | Plan Accuracy (potential) mm | Height Accuracy (potential) mm |
|---|---|---|---|---|---|---|---|---|
| Medium format | Hass H6D-100c Phase One XF IQ4 | 100 | 50 | 25 | 750 | 2.3 | 3 | 11 |
| | | 100 | 50 | 50 | 190 | 4.6 | 5 | 22 |
| | | 100 | 50 | 100 | 50 | 9.2 | 10 | 43 |
| 35mm DSLR | Canon D810 | 36 | 35 | 25 | 900 | 3.5 | 4 | 17 |
| | | 36 | 35 | 50 | 225 | 7.0 | 7 | 34 |
| | | 36 | 35 | 100 | 60 | 14.0 | 14 | 68 |

Table 1

For feature extraction there are now automatic algorithms that can be utilised with numerous software packages available that accommodate this approach. For example for a railway mapping project, the height of the crown of a rail and plan position of the edge of the rail can be automatically extracted from the 3D point cloud. BIM models and topographic mapping can also be extracted from the point cloud.

To verify the accuracy, Ground Truthing Points (GTP) or Data Validation Points (DVP) will be required at regular intervals throughout the site and surveyed with a total station. Ground control points deployed for the photogrammetric process should not be used for these GTP or DVP. Additional control points will need to be collected and only used as an accuracy check against the photogrammetry results. These may be collected at the time of the aerial survey, or be derived from previously collected data or third party information, provided that there is high confidence in the quality of this data and that it satisfies the project accuracy requirements. For the example shown in Figure 15, ground truthing points were placed at approximately 10m intervals.

In addition to improved accuracy the high resolution photography allows for a greater precision for interpretation, for example for a railway survey, identification of the markings on sleepers, rail clips, and crossing noses can be achieved. This all helps in removing the need for on site surveys with the ability to obtain infrastructure information remotely.




Figure 15
Vogel R3D SUA system comprising of an Aerialtronics Altura Zenith ATX8 industrial UAV and 100 megapixel Phase One IXU1000 camera, with an extract of topographic survey.

## 7.2 Four Steps to a successful SUA Photogrammetric Survey

It is easy to succumb to a low cost SUA based solution, but to guarantee quality and results for the photogrammetric processing of Small Format Aerial Photography (SFAP), the following guidelines should be considered:

1. The SUA – Safely, reliably and accurately position the camera with built in redundancy to overcome sudden loss of power and communication

2. The Camera – for high quality mapping, a high quality camera, avoid very wide angle or telephoto lenses to minimise distortion and artefacts

3. The Surveyor – Flight planning and ground control is critical to ensure that the photogrammetric products can be achieved to the expected standard. To verify the accuracy, independent ground control and data validation points will be required at regular intervals throughout the site

4. The Pilot – The pilot is not always a surveyor but needs to understand and follow the survey flight plan and must be aware of and adhere to Civil Aviation Authority (CAA) legislation. The pilot needs to have a CAA Licence for the weight of the SUA being flown (<7kg or <20kg) and Public Liability insurance must be in place.



Figure 16
3D city modeling from images taken from Track Air Octoblique MIDAS "9 camera rigs" and processed automatically with Pix4Dmapper.

## 8. 3D City Modelling

Multi image nadir and oblique cameras are available to capture 3D city models as shown in Figure 16.

These multiple oblique image concepts such as Octoblique MIDAS contain 8 oblique cameras spaced at 45 degrees to complete a 360 degree view without blind spots as shown in Figure 17.

The imagery results in 8 views from various stations that cover the Nadir view in the centre. It acquires images at an interval of less than 1 second producing a fully 3D aerial capture reality in a single flight. It is made possible by having a stabilised suspension system allowing the cameras to move freely without the need for a bulky old fashioned circular mount. The powerful computer control centre operates the cameras, IMU, navigation mount and power to the system.

Off the shelf high end SLR cameras are used instead of expensive medium format cameras.

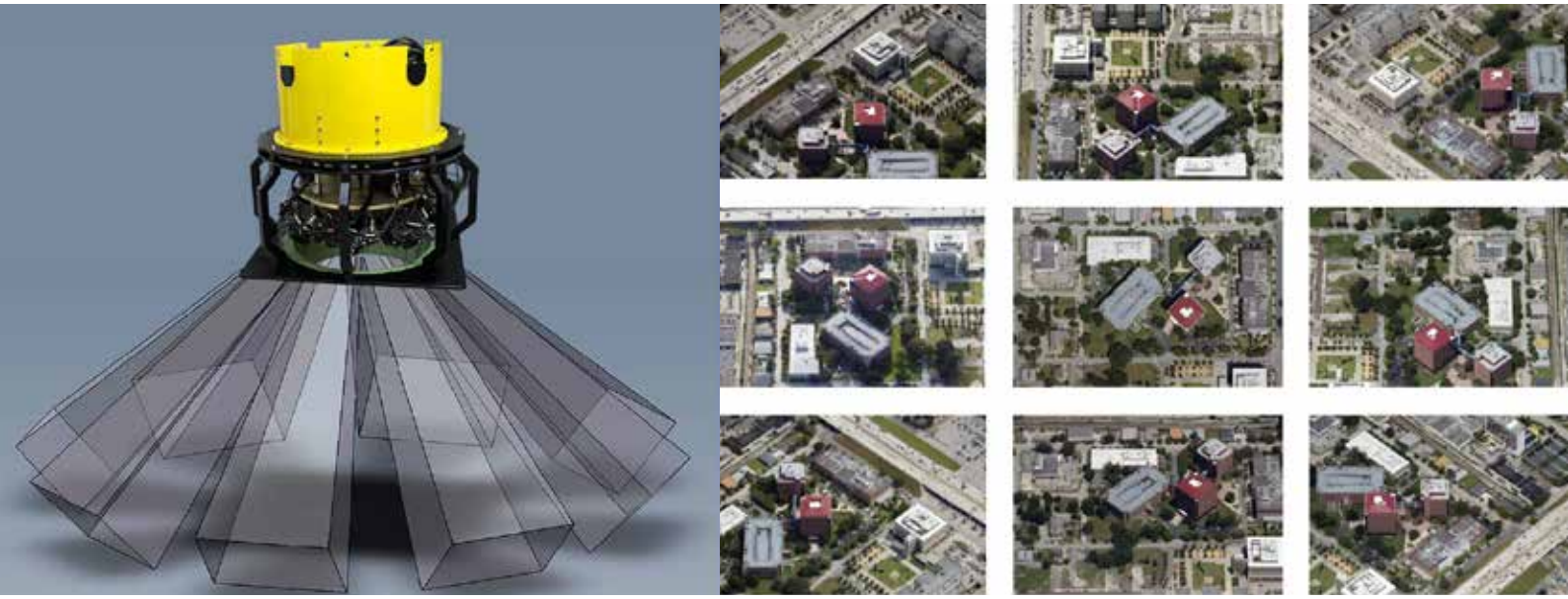


Figure 17
Track Air Octoblique MIDAS camera configuration and resulting image views.

## 9. Earth Observation Photogrammetric Solutions

State of the art industrial geo-production systems are available to produce a wide range of cartographic products covering mapping, planning, defence, security and disaster management as shown in Figure 18.

With almost 200 remote sensing spacecrafts in orbit or planned, over 200 digital cameras in use, the increase in SUA solutions, several thousand terabytes of data need to be processed annually. This increasing demand is forcing industrial production methods.

Multi Sensor inputs allow for Multi Product outputs in the form of DSM, DTM Ortho images, True Ortho images, Cloud free mosaics, 3D TIN models and 3D City models.

A Digital Surface Model (DSM) is a representation of the earth's surface and all points on it such as buildings, bridges and trees. A Digital Terrain Model (DTM) is a representation of the bare ground surface with no objects present. The creation of a DTM usually

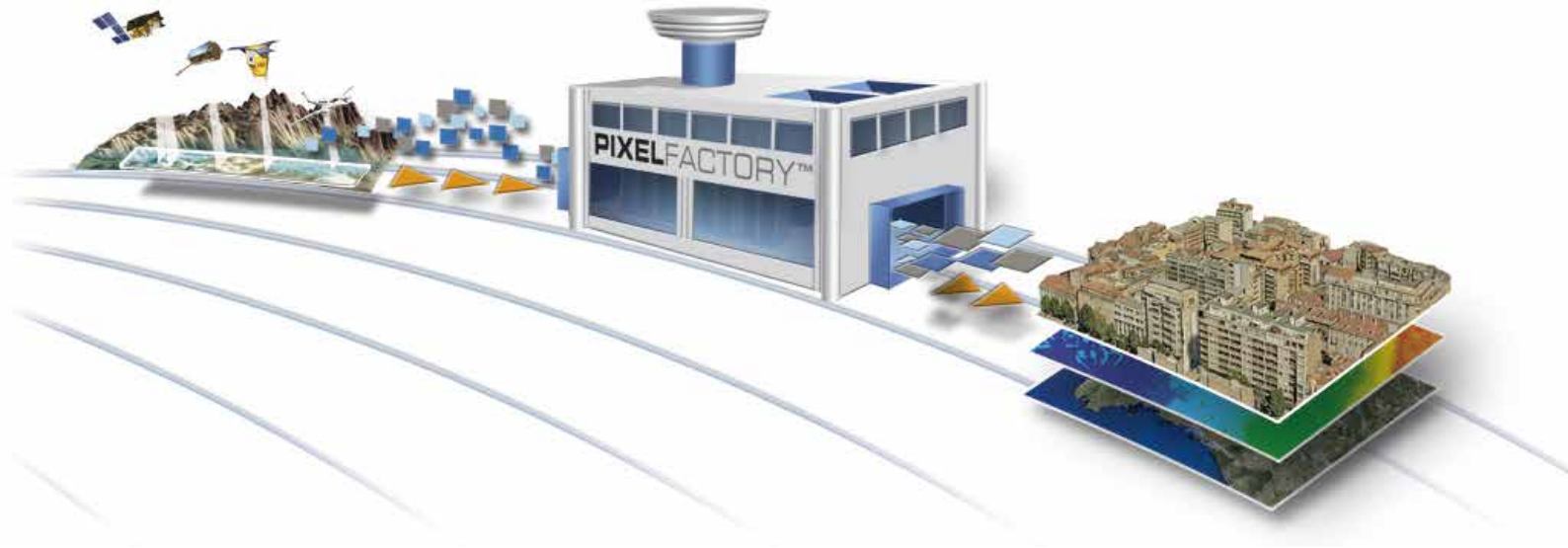



Figure 18
Pixel Factory Neo providing industrial scale photogrammetric production

requires an initial process of filtering to remove these features and an interpolation of the hidden surface. This is followed by a quality assurance and editing phase to remove anomalies or features that have not been automatically removed by the process. Figures 19 and 20 show the fundamental difference between a DSM and a DTM.

The cross sections in Figure 21 also show the difference between a DSM and a DTM.

High performance and intuitive open architecture allow for automatic processing of vast volumes efficiently. This system is adaptable, can be deployed inside a private Cloud, and has flexibility to interface with existing third party software and tools.

Figure 19 (left)
**DSM**

Figure 20 (right)
**DTM**

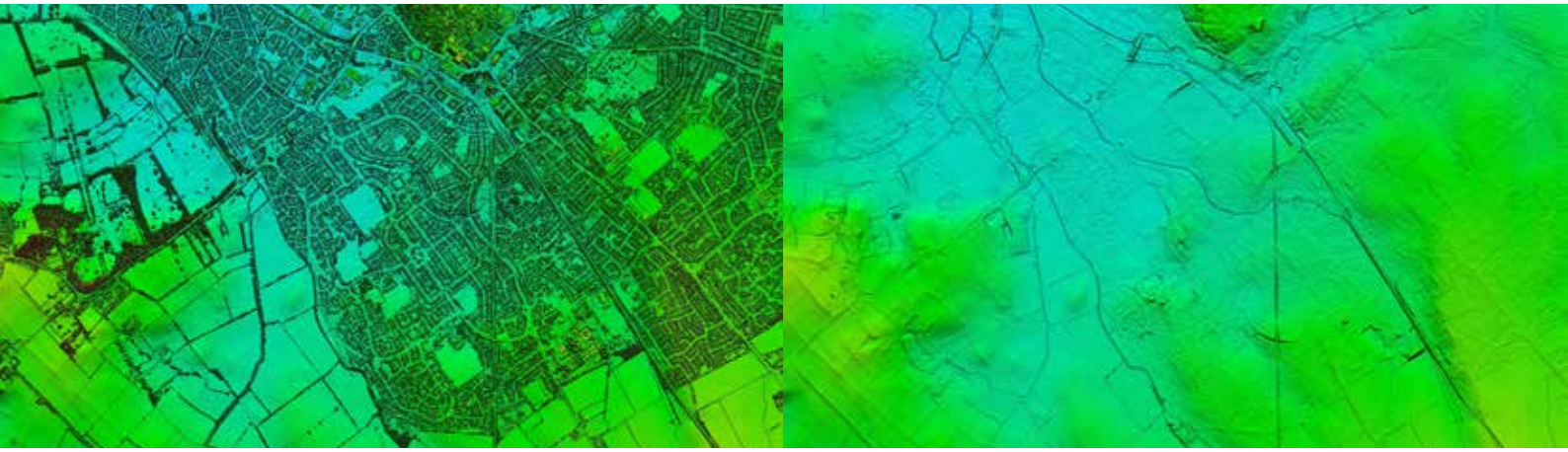
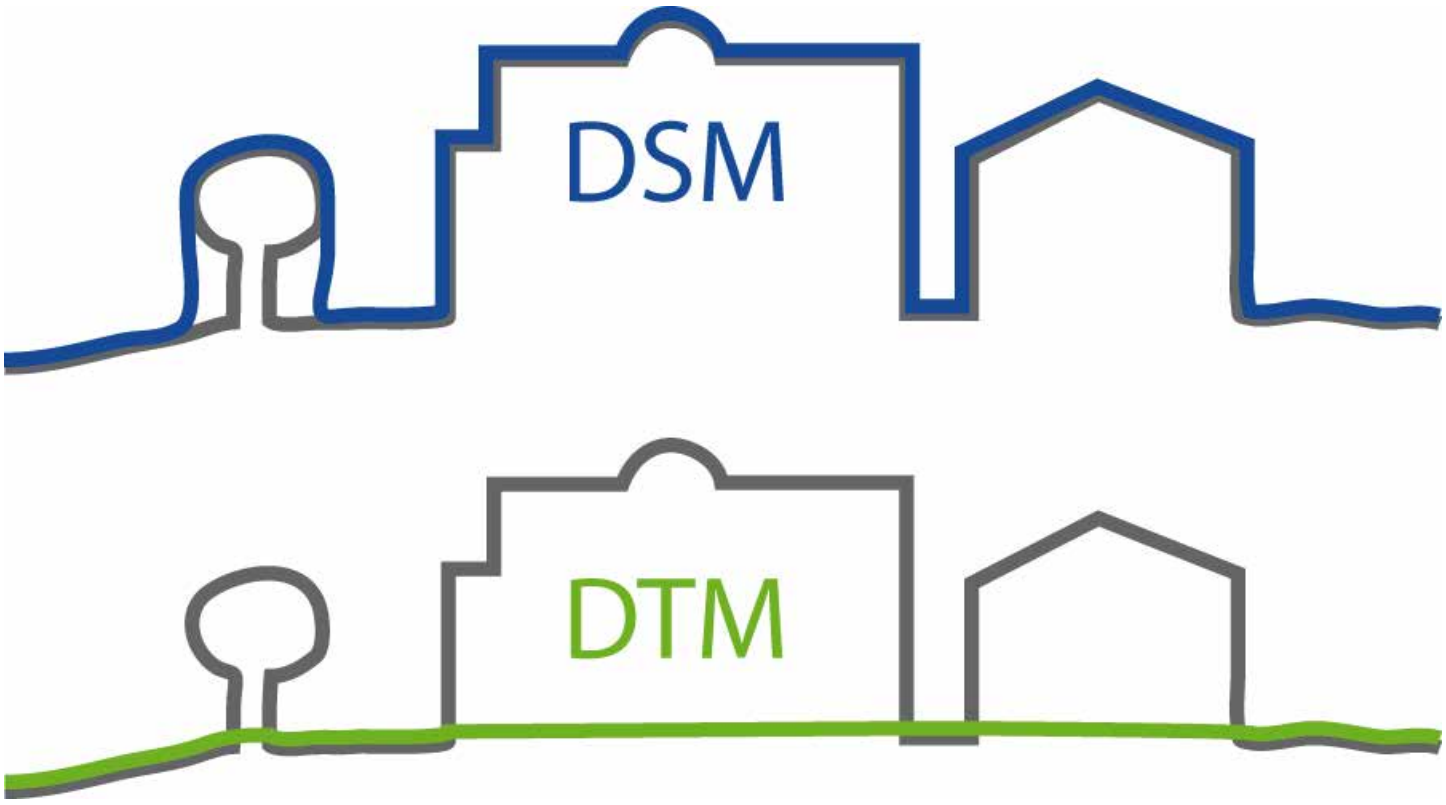


Figure 21
**DSM/DTM**



## 10. Workflow Example

A generalised workflow for multi-image methods is as follows:

- Planning – what is the end product? Any doubts should be discussed with a contractor
- Camera calibration – for higher precision work
- Fieldwork
    - Control point survey
    - Photography Check for quality and coverage
    - Height checks of critical known values e.g. heights of cars and lamp-posts
- Basic image processing only – brightness, contrast
- Image selection for the project
- Photogrammetry
    - Self or pre-calibration (inner orientation)
    - Image orientation/triangulation (relative orientation)
    - Constraint to area of interest
    - Control input, observation and transformation (absolute orientation)
    - Process dense match
    - Process mesh
    - Process texture
    - Process orthophotograph if required
    - Collect vector data if required
    - Export products
- Further processing in other packages, for example to improve the mesh, vectorisation, product presentation and archiving
- Survey report. The photogrammetric deliverables should also include a survey report. This will outline the following:
    - Project brief
    - Methodology, planning and dates of data capture
    - Fieldwork collection with diagrams and photographs
    - Processing statement with results, accuracies and residual errors
    - QA reports
    - Description of deliverables with examples
    - Details of any problems encountered, resolved and any other useful information

## 11. Photogrammetric Applications

The extent of potential photogrammetric applications is limited only by imagination. The benefit derived from such a mass data collection technique allows it to be

archived for potential later use, especially in the documentation of threatened objects or landscapes. This mass of data also means that secondary analysis can take place or features can be extracted that weren't required initially. This is not the case with conventional survey techniques where a decision has to be made, during the fieldwork, of the relevance of a feature. Below is a non-exhaustive list of applications:

- Topographic mapping at all scales
- Urban and route planning
- Asset management
- Vegetation and land use mapping
- Change detection
- Length, area and volume measurements
- Architectural survey
- Archaeological survey
- Engineering and building analysis
- 3D modelling and printing
- Animation
- Insurance and archival recording
- Orthophotography
- Flood Mapping
- Emergency response
- Surveillance

## 12. Summary

The advantages and disadvantages of photogrammetry can be summarised as follows:

### Advantages

- The high quality imagery provides a permanent archival record
- Capture of layered CAD and surface data directly from the imagery
- 2D or 3D information options
- Non-contact and non-intrusive
- Field operation times are lower than all other methods for the amount of data normally captured
- Old imagery can be compared to new data for change detection
- Rapid results for basic or critical information
- Records detail of a complex nature
- High levels of resolution and precision
- Very cost effective for multi-image methods

### Disadvantages

- In its stereo form it is a complex technique – but automated methods (as described) are readily available
- The very high standards of precision may not be required
- Value of the information may not warrant the cost
- Interpretation of detail – a subjective selection is made by the photogrammetric operator and not the expert in archaeology, for example. This is now less of an issue as the new multi-photo methods are partly aimed at the end user of the data
- Laser scanning may be more cost effective if only a surface or unstructured model is required

## 13. References and Further Reading


De Luca, L., Veron, P. and Florenzano, M. (2006). Reverse engineering of architectural buildings based on a hybrid modeling approach. Computers & Graphics, 30(2), 160-176.

RICS Vertical Aerial Photography and Derived Digital Imagery 5th edition Guidance Note 2010 (GN 61/2010) at: http://www.rics.org/uk/knowledge/professional-guidance/guidance-notes/vertical-aerial-photography-and-digital-imagery1

Historic England (2015). Metric Survey Specifications for Cultural Heritage (3rd Edition) at: https://historicengland.org.uk/images-books/publications/metric-survey-specifications-cultural-heritage

Luhmann, T and Robson, S (2011) Close Range Photogrammetry: Principles, Methods and Applications.

TSA Guides at: www.tsa-uk.org.uk/downloads

The software suppliers provide guides, tutorials, blogs, FAQs, etc on their websites:

www.agisoft.com

https://www.bentley.com/en/products/brands/contextcapture

https://pix4d.com/

www.photomodeler.com


## 14. Acknowledgements


- Obaid Alblooshi
- Bentley Systems Inc
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- Leica Geosystems
- Samsung Group

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- Getty Conservation Institute
- The University of Nottingham
- IIC Technologies Ltd
- Pix4D
- TSA
- Plowman Craven
- Geomatics World
- Track Air

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Revised by Ned Chisholm MRICS

## 15. Tendering Considerations

When procuring surveys by photogrammetry the following information should be provided to the tenderer:

- The purpose of the survey
- The specification including any special requests
- A plan with the survey area outlined
- The expected accuracy of the deliverable products
- Information on the survey environment and conditions, for example: health and safety issues, access arrangements or security problems
- Deliverable data formats

## 16. Tender Returns

A company practised in photogrammetric surveys can usually submit a proposal efficiently and a client should insist on the following details to be included in the quotation as a minimum:

- A start date for the survey work
- Delivery dates for the final data and any interim deliverables
- The survey company's terms and conditions
- A method statement and risk assessment to understand the procedures the company uses during the course of the project
- A provision for a weekly progress report to allow for any changes in programme and resource re-allocation

The process of commissioning and successfully completing a photogrammetric survey is straightforward if the guidelines above are followed. One key element is to use a survey company that has experience with this type of work and is a member of TSA.

## 17. The Survey Association

Formed in 1979 as The UK Land and Hydrographic Association, TSA is now established as the representative organisation for UK private surveying firms. The Association's aims are:

> To provide a vehicle for members to act effectively together on agreed courses of action.

> To promote the interests of the profession to all those who determine the economic and social conditions in which the industry operates.

> To identify and represent the views of the industry.

## 18. Using a TSA Member

By using a TSA member you can be assured that your project will get off to the best possible start. Whatever the size of project, you can be certain that TSA member companies are expert in the provision and management of spatially related data on which to base your concept, design and construction.

Professional attention from a TSA surveyor will reduce risk, repetition, possibly save you money and will ensure that your project receives the best possible attention.

## 19. TSA Contact Details

If you would like any more information about the TSA or its members or about other Information leaflets then please contact TSA at:

**The Survey Association**
The Survey School, 79 Waterworks Road, Worcester WR1 3EZ

Tel: **01905 26329**

Email: **office@tsa-uk.org.uk**

Website: **www.tsa-uk.org.uk**

## 20. TSA Disclaimer

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## 21. Glossary of Terms

| TERM | EXPLANATION |
|---|---|
| CAA | Civil Aviation Authority |
| CAD | Computer Aided Design or Drafting |
| EV | Exposure value – camera setting for adjusting the exposure temporarily |
| GNSS | Global Navigation Satellite System – a satellite based navigation system with global coverage |
| GSD | Ground Sample Distance – the size of a pixel at true scale |
| IMU | Inertial Measurement Unit which forms part of an INS (Inertial Navigation System) |
| ISO | International Organisation for Standards – in this context it is a measure of the sensitivity of the sensor |
| JPEG | Joint Photographic Experts Group who devised a widely used method of image compression |
| SFAP | Small Format Aerial Photography |
| SfM | Structure from Motion – computer vision term for the automated and semi-automated 3D modelling software from imagery |
| SUA | Small Unmanned Aircraft |

### Document revision history

| | | |
|---|---|---|
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| Issue 2 | October 2018 | Revisions |