

High-Resolution Urban True Orthoimagery Standard

Interim Project Report

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Submitted to

Chair, Julie Binder Maitra
FGDC Standards Working Group
FGDC Secretariat
590 National Center
Reston, VA 20192

By

Guoqing Zhou,
Old Dominion University;
Tel: (757) 683-3619; Fax: (757) 683-5655; E-mail: gzhou@odu.edu

Robin Fegeas,
Mapping Applications Center, USGS, Reston, VA 20192

Hap Cluff
Department Information Technology
City of Norfolk, Norfolk, VA 23510

Jeann Foust
ESRI Corporate,
380 New York Street, Redlands, CA 92373-8100

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Executive Summary

This is an interim project report, which summarizes our progress from July 2009 to December 2009 on the project, entitled “High-Resolution Urban True Orthoimagery Standard” funded by the NSDI Cooperative Agreements Program. This project has produced significant progress in the first half project year. A draft of high-resolution urban true orthoimagery standard has been made. This draft of the Standard is primarily oriented toward the production of 6-inch or one-foot gray and color–infrared high-resolution digital orthoimagery in urban area. This standard describes process, accuracy, and quality control for urban high-resolution (e.g., 6-inch or one-foot) digital orthoimagery. This standard is classified as a National Spatial Data Infrastructure by the Federal Geographic Data Committee (FGDC).

Project Narrative

A high-resolution digital orthoimagery is a geo–referenced image in which the displacements caused by the terrain and objects, and distortions caused by sensor orientation error, lens distortion, earth curvature, and atmosphere refraction should completely be orthorectified in its correct, upright, planimetric position. Thus, high-resolution orthoimagery should theoretically be a spatially accurate image with ground features represented in their **TRUE** planimetric positions. This means that the tall buildings (e.g., houses, tower) in high-resolution digital orthoimagery should not appear to lean over a street or other lower features, and the roofs of the buildings should not appear twice, called “ghost image”, and tall building should not occlude the low building.

Many investigations have demonstrated that the procedures and algorithms used early are not appropriate for high-resolution urban orthoimagery generation and the impacts of the problems have significantly influenced the usefulness of the orthoimagery in industry because of the error of these incomplete orthorectification (Zhou et al. 2005). With rapidly increasing applications to high-resolution (e.g., 6-inch and one-foot) orthoimagery in government agency, industry sector and academia, the objectives of this standard specified in this document are

- (1) Establish the technical criteria to be used in the production of high-resolution orthoimagery in urban area.
- (2) Set a common procedure and process for producing high-resolution orthoimagery to ensure the accuracy and quality of national orthoimagery spatial data infrastructure.
- (3) Partially amend the existing standard with emphasis on the process, method, accuracy and quality control of high-resolution orthoimagery in urban area.
- (4) Set a common baseline to facilitate the interchange and widest utility of digital orthoimagery data for urban area.
- (5) Provide USGS components with guidelines for performing quality control and acceptance of high-resolution digital orthoimagery data into the *National Digital Cartographic Data Base* (NDCDB). Urban high-resolution orthoimagery produced by other federal, state and local government agencies, the private sector, must conform to this standard, and to be accepted for entry in the *National Digital Cartographic Data Base* (NDCDB).

In the last half project year, this project has held two tele-conferences. One tele-conference was taking place on November 12, 2009. The second tele-conference was on December 8, 2009. In

the beginning of project, a proposal of project activities was written by the Principal investigator (PI), and reviewed by two peer-reviewers specified by Federal Geographic Data Committee.

With different inputs and comments from reviewers, a draft of high-resolution urban true orthoimagery standard has been produced. This draft of the Standard describes process, accuracy, and quality control for urban high-resolution (e.g., 6-inch or one-foot) digital orthoimagery in urban area. This Standard is different from the existing Standards such as (1) *Digital Orthophoto Standard* formulated by the National Digital Orthophoto Program (NDOP) (USGS, 1996). This Standard consists of Part I, General; Part II, Specifications; (2) *Content Standards for Digital Orthophoto*, formulated by the *Federal Geographic Data Committee* (FGDC, 1999), (3) Digital Orthophoto Program formulated by USGS in 1998 (USGS, 1998), (4) Standards for 1:12,000-scale orthophoto quarter-quadrangles (USGS, 1991), and (5) Standards for 1:24,000-scale orthophoto quadrangles (USGS, 1992). These Standards above have not considered the specifications of high-resolution orthoimagery generation in urban area because the early procedures were based on earlier USGS mapping operations, such as 2.5-D digital elevation models (DEMs). It has been demonstrated that such procedures, especially, application of 2.5-D DEM, has caused uncompleted orthorectification, even error, e.g., ghost image (Zhou et al. 2005).

A detailed draft of Standard is attached below.

Future Work:

With the half project year's effort, the future work is planned as follow:

- From January 1 2010 - March 30, 2010, a detailed technical verification and improvement for the draft of Standard will be conducted, and
- From March 1, 2010 to June 30, 2010, the evaluation and promotion will be made for the new Standard.

Project members

PI: Guoqing Zhou, Old Dominion University

Co- Is:

Robin G. Fegeas, Mapping Applications Center, USGS

Hap Cluff, Dept. of Information Technology, City of Norfolk

Jeanne Foust, Environmental Systems Research Institute (ESRI) Inc.

Support team from USGS and Federal Geographic Data Committee

Gita Urban-Mathieux

NSDI CAP Coordinator

Federal Geographic Data Committee

Julie Binder Maitra

Federal Geographic Data Committee (FGDC)

Chair, FGDC Standards Working Group

International Representative, INCITS Technical Committee L1,

Geographic Information Systems

1. INTRODUCTION

1.1 SCOPE

This Standard is primarily oriented toward the production of 6-inch or one-foot gray and color–infrared high-resolution digital orthoimagery in urban area.

This standard describes process, accuracy, and quality control for urban high-resolution (e.g., 6-inch or one-foot) digital orthoimagery. This standard is classified as a National Spatial Data Infrastructure by the Federal Geographic Data Committee (FGDC).

1.2 OBJECTIVES

Many investigations have demonstrated that the procedures and algorithms used early are not appropriate for high-resolution urban orthoimagery generation and the impacts of the problems have significantly influenced the usefulness of the orthoimagery in industry because of the error of these incomplete orthorectification (Zhou et al. 2005). With rapidly increasing applications to high-resolution (e.g., 6-inch and one-foot) orthoimagery in government agency, industry sector and academia, the objectives of this standard specified in this document are

- (6) Establish the technical criteria to be used in the production of high-resolution orthoimagery in urban area.
- (7) Set a common procedure and process for producing high-resolution orthoimagery to ensure the accuracy and quality of national orthoimagery spatial data infrastructure.

- (8) Partially amend the existing standard with emphasis on the process, method, accuracy and quality control of high-resolution orthoimagery in urban area.
- (9) Set a common baseline to facilitate the interchange and widest utility of digital orthoimagery data for urban area.
- (10) Provide USGS components with guidelines for performing quality control and acceptance of high-resolution digital orthoimagery data into the National Digital Cartographic Data Base (NDCDB). Urban high-resolution orthoimagery produced by other federal, state and local government agencies, the private sector, must conform to this standard, and to be accepted for entry in the National Digital Cartographic Data Base (NDCDB).

1.3 HIGH-RESOLUTION DOI DESCRIPTION

A high-resolution digital orthoimagery is a geo-referenced image in which the displacements caused by the terrain and objects, and distortions caused by sensor orientation error, lens distortion, earth curvature, and atmosphere refraction should completely be orthorectified in its correct, upright, planimetric position. Thus, high-resolution orthoimagery should theoretically be a spatially accurate image with ground features represented in their **TRUE** planimetric positions. This means that the tall buildings (e.g., houses, tower) in high-resolution digital orthoimagery should not appear to lean over a street or other lower features, and the roofs of the buildings should not appear twice, called “ghost image”, and tall building should not occlude the low building.

1.4 NECESSITY TO THE EXISTING STANDARD AMENDMENT AND REVISION

The existing Standards related to this Standard include (1) *Digital Orthophoto Standard* formulated by the National Digital Orthophoto Program (NDOP) (USGS, 1996). This Standard consists of Part I, General; Part II, Specifications; (2) *Content Standards for Digital Orthophoto*, formulated by the Federal Geographic Data Committee (FGDC, 1999), (3) Digital Orthophoto Program formulated by USGS in 1998 (USGS, 1998), (4) Standards for 1:12,000-scale orthophoto quarter-quadrangles (USGS, 1991), and (5) Standards for 1:24,000-scale orthophoto quadrangles (USGS, 1992).

The Standards above have not considered the specifications of high-resolution orthoimagery generation in urban area because the early procedures were based on earlier USGS mapping operations, such as 2.5-D digital elevation models (DEMs). It has been demonstrated that such procedures, especially, application of 2.5-D DEM, has caused uncompleted orthorectification, even error, e.g., ghost image (Zhou et al. 2005).

1.5 APPLICABILITY

This standard applies to urban high-resolution digital orthoimagery produced, or disseminated by or for the USGS. Federal agencies, state agencies, local agencies, academia, and private sectors producing high-resolution orthoimagery, either directly

or indirectly (e.g. through grants, partnerships, or contracts with other entities), shall ensure that data meets all relevant standards.

1.6 TERMS AND DEFINITIONS

Definitions applicable to this Standard are listed below. Other terms and definitions used in this Standard can be referenced to other Standards.

Data Structure – is a particular way of representing, storing, organizing and managing data in a computer so that it can be efficiently accessed and used.

Data Model – describes how a group of data is represented and accessed. It formally defines data elements and relationships among data elements for a domain of interest.

Digital Building Model (DBM) – is a type of data model of describing the surface of man-made object details. A real three-dimensional representation of digital building details would lead to a much more complex data structure than that generally used for digital terrain model (DTM).

DBM-based orthoimagery – refers to the orthoimagery generated using DBM model to orthorectify only the displacement caused by buildings without accounting for displacement caused by terrain.

Digital Surface Model (DSM) – is a mode of representing the entire surface of the observed region. Therefore, the DSM is a combination of DTM (digital terrain model) and DBM (digital building model). A DTM and one or more DBMs may concurrently exist at the same geographical position, for instance at a bridge (DTM plus bridge DBM). A DSM is indeed a 2.5 dimensional data, where each point (represented by x and y values) has only one elevation value (z). When the edge of a tall object lies inside a pixel, the pixel has an average elevation value between the ground and the object's top elevations. Thus, the objects heights are not represented well as they are in the reality.

Digital Terrain Model (DTM) – is an elevation model that describes the surface of the naked terrain without buildings and vegetation.

DTM-based Orthoimagery – refers to the orthoimagery in which the relief displacement caused only by terrain is orthorectified without considering the displacement caused by buildings.

Geometric Accuracy – is used for accuracy measure of target position in a given datum (or coordinate system).

Geometric Resolution (Spatial Resolution) – refers to the physical size of an individual pixel with smaller pixel sizes corresponding to higher geometric resolution in ground.

Master Orthoimagery (MOI) – is orthoimagery that is taken primary imagery with which the other orthoimagery are referenced to when compensating the occluded area.

Near True Digital Orthoimagery (NTDOI) – refers to the orthoimagery that contains black patches, which represent occluded objects when merging the DBM-based orthoimagery and DTM-based orthoimagery.

Orthoimagery Patch – refers to the patch of an orthoimagery that is used to fill out the occluded and shadowed areas of a master orthoimagery. A digital orthoimagery may be made up of several images mosaicked together to form the final image. Each separate piece of the mosaic that contributes to the final image is called a "patch".

Slave Orthoimagery (SOI) – is orthoimagery that is used as compensation of the occluded patches in the master orthoimagery.

Triangulated Irregular Network (TIN) – is a vector data structure used for the representation of a terrain surface in spatial information science using a group of irregularly distributed triangulations composed of nodes and lines.

True Orthoimagery (NDOI) – a geo-referenced image in which the displacements caused by the terrain and objects, and distortions caused by sensor orientation error, lens distortion, earth curvature, and atmosphere refraction should completely be

orthorectified in its correct, upright, planimetric TRUE position. The tall buildings would not lean over, or occlude a street or other lower features, and appear ghost image.

1.7 SYMBOLS, ABBREVIATED TERMS, AND NOTATIONS

The following NEW symbols, abbreviations, and notations are applicable to the Digital Orthoimagery.

DTM – Digital Terrain Model

DBM – Digital Building Model

DSM – Digital Surface Model

DOI – Digital Orthoimagery

NTOI – Near True Orthoimagery

SOI – Slavery Orthoimagery

TOI – True Orthoimagery

TIN – Triangulated Irregular Network

2. HIGH-RESOLUTION DIGITAL ORTHOIMAGERY PROCESS

2.1 BASIC STEPS OF HIGH-RESOLUTION ORTHOIMAGERY GENERATION

In order to orthorectify the relief displacement caused by buildings onto its correct, upright, true positions, the buildings must be represented as part of the surface to be rectified. On the other hand, the relief displacement caused by terrain must also be

orthorectified onto their true positions. So, an exact representation of terrain should be given, i.e., digital terrain model (DTM), which does not contain buildings and vegetation. Therefore, the basic steps of true orthoimagery generation must include both DTM-based orthoimagery generation and DBM-based orthoimagery generation as well as the merging of DTM- and DBM-based orthoimagery, as well as other works, such as occlusions detection and compensation, and shadow detection and removal (Figure 1).

2.2 DATA INPUT

Production of high-resolution digital orthoimagery requires several types of inputs to produce an orthogonally rectified imagery from the original perspective imagery captured by the sensor. These inputs include: 1) the unrectified raster raw imagery scanned from the diapositive or directly acquired from a digital sensor, 2) sensor orientation elements including interior orientation elements (IOEs) (focal length, principal point coordinates, lens distortion parameters), and exterior orientation elements (EOEs) (three position elements and three angle elements), 3) well-distributed ground control points, 4) a digital terrain model (DTM) with the same area of coverage as the digital orthoimagery, 5) a digital building model (DBM) with the same area of coverage as the digital orthoimagery, and 6) other parameters such as datum, reference coordinate system, earth curvature, etc.

2.3 DIGITAL BUILDING MODEL (DBM)

For production of a high-resolution (e.g., one-foot, or 6-inch) orthoimagery, tall buildings (e.g., tall house, water tower, TV tower, etc.) can clearly be displayed in the raw imagery. In order to not cause ghost imagery, and/or occlusion to other buildings in the orthoimagery, those buildings with roofs having an aerial coverage of 10 square feet or greater should be represented and managed by a type of data structure, i.e., digital building model (DBM). Moreover, buildings should be delineated by tracing the apparent edge of the roofline. The compiled data should have the elevation of the roof line. In other words, all of extracted buildings should be modeled in 3D, and stored into DBM database. So, this work consists of (a) data structure and the topological relationship of the spatial object for managing urban building objects; (b) effective database management technology to manage the data; (c) effect access of the digital building data for orthoimagery production.

2.4 DIGITAL TERRAIN MODEL (DTM)

Digital Terrain Model (DTM) is an elevation model that describes the surface of the terrain without buildings and vegetation. USGS DEM with raster (grid) data structure has been a commonly accepted data form for use in production of orthoimagery. However, a triangulated irregular network (TIN) vector data structure composed of a group of irregularly distributed triangulations, i.e., nodes and lines with the three dimensional coordinates (x, y and z) that are arranged in a network of triangles is also capable of modeling the urban terrain surface. It has also been demonstrated that the vector TIN has sufficient accuracy for complex urban terrain orthorectification, since an advantage of using a TIN over a DEM in complex urban area is that the points of a

TIN are distributed variably so that it has capability of accurate representation of the terrain in a complicated urban area. Moreover, the Data input is therefore flexible and fewer points need to be stored than in a DEM.

2.5 DBM-BASED ORTHOIMAGERY GENERATION

The generation of DBM-based orthoimagery uses DBM model to orthorectify only the displacement caused by buildings, thus it does not account for displacement caused by terrain, i.e., any other imagery data of the surrounding terrain. For urban area, the treatment of all sorts of occlusions: buildings occluding terrain and tall buildings occluding low buildings will have to be considered. Additionally, because occluded buildings cannot be orthorectified, this step leaves holes in the orthoimagery. These occluded areas should be marked as black, i.e., setting their brightness value to 0. This means that areas occluded by objects need to be filled by using other orthoimagery, called *slave orthoimagery*. The above generated orthoimagery contains buildings only, and is thus called a *DBM-based orthoimagery*. The accuracy of DBM-based orthoimagery generation should be less than 1.0 pixel.

2.6 SLAVE ORTHOIMAGERY (SOI)

For a tall building urban area, it usually creates several DBM-based orthoimagery using several raw images with the same DBM data. One DBM-based orthoimagery with high orthorectification accuracy, and centralizing at the major building is taken as primary orthoimagery, and one or more other DBM-based orthoimagery is/are referenced to the primary orthoimagery and is/are used to fill the occluded areas when

compensating the occluded areas. These orthoimagery are usually called “slave” orthoimagery.

2.7 DTM-BASED ORTHOIMAGERY GENERATION

The generation of DTM-based orthoimagery is for orthorectifying the relief displacement caused only by terrain without considering the displacement caused by buildings. The method of DTM-based orthoimagery would traditionally be implemented either by top-down or down-top method. The data to be used for DTM-based orthoimagery generation can be either from the grid DEM or vector TIN, with less than 1.0 pixel error.

2.8 NEAR TRUE ORTHOIMAGERY

With the DBM-orthoimagery and DTM-based orthoimagery, an intermediate orthoimagery should be produced by merging the DBM-orthoimagery and DTM-based orthoimagery. The resulting orthoimagery at this step still contains the black patches, which represent occluded objects and areas, and will be compensated. This intermediate orthoimagery is thus called *Near True Orthoimagery (NTOI)*.

2.9 OCCLUSION DETECTION

In highly density urban area, the tall buildings usually occlude low buildings and terrain. For the areas containing tall buildings located near the margin of the imagery, where skew viewing by the imaging camera makes occlusions larger. To solve this problem, a unique solution is the detection of the occluded area, and compensation of

the occluded area using cross-strip imagery and along-strip imagery with over 75% overlap. Detection error of the boundary of the occluded area should be less than 1.0 pixel.

2.10 OCCLUSION COMPENSATION

All the occluded areas have to be filled by the orthoimagery patches from “slave” orthoimagery. The process of occlusion compensation requires finding conjugate areas in adjacent slave orthoimages and then filling the occluded area using orthoimagery patches. In addition to needing a considerable overlap between aerial images, the optimization of seam lines, and optimization of orthoimagery patches are considered as well. For the optimization of seam lines, the boundary should not fall on ground features such as cars, building, roads, or shadows; for the optimization of orthoimagery patches, the qualities of orthorectification of an identical ground object in different orthoimagery are different. Picking the best patches from the slave orthoimagery should be optimized. If possible, the patches should be close to nadir point position as could as possible.

2.11 SHADOW DETECTION

Aerial imagery in urban area usually exposures shadow. Shadow detection is required to restore the shadowed areas. The shadowed areas should be detected with a vector representation of the shadow boundary with sufficient accuracy.

2.12 SHADOW REMOVAL AND RECOVERY

The shadowed area should be substantially restored and the imagery quality of these shadowed areas is comparable to the ones around them. The effectiveness of shadow removal can also be demonstrated by their histograms analysis, with which the mean and dynamic ranges of the data in the shadowed areas become comparable to those in the non-shadowed areas after shadow treatment.

3. MOSAIC OF ORTHOIMAGERY

Final product of orthoimagery may be created by mosaicking multiple orthoimagery. A mosaicked orthoimagery should theoretically be seamless in geometry and radiometry. In high-resolution urban area, spectral reflections for tall building, long bridge, water tower, TV tower, etc. may in practice cause the cutlines due to radiometric differences between the orthoimagery involved. Optimization of seamline should be conducted to minimize, even eliminate seamline, and mismatches.

3.1 SEAMLINER OPTIMIZATION

In urban area, especially density urban area, a variety of features, such as tall buildings, bridges, car, etc appear on the image. The occlusion is another important feature in urban area. The seamline for mosaicking two adjacent orthoimagery should avoid to fall on ground features such as buildings, bridges, or shadows, which probably have different brightness values in the individual orthoimagery because the

occlusion identification is based on the geometry of imaging system, not on image radiometry.

3.2 RADIOMETRIC BALANCE

When compensating the occluded areas and mosaicking two or more orthoimagery, the brightness and color values of the patches to be compensated and orthoimages should be adjusted to match that of the principal orthoimagery. The seamlines between the overlapping patches should be optimized to minimize tonal variations. Localized adjustment of the brightness and color values should be conducted to reduce radiometric differences between joined areas. Changes in color balance across the project, if they exist, shall be gradual. Abrupt tonal variations between two orthoimages are not acceptable.

4. ORTHOIMAGERY QUALITY CONTROL

The orthoimagery should be quality controlled at all stages and be free from distortions at bridges and other buildings, free from the edges matched, free from double imagery 'ghosting' effect for tall buildings, seamless at mosaicked edges, sharp without blurring effect and sharp uniform balanced color contrast consistently across entire orthoimagery. The generated orthoimagery should be verified by both radiometric validation and geometric accuracy validation using both visual check and check points.

4.1 RADIOMETRIC VISUAL CHECK

Orthoimagery brightness values may deviate from the brightness values of the original imagery due to the image resampling during orthorectification processes. Radiometric accuracy will be verified by visual inspection of the orthoimagery with the original unrectified imagery to determine if the digital orthoimagery has the same imagery quality as the source imagery(s). Visual check of the orthoimagery should be conducted through the items below.

- Completeness of data to cover the project area, with no omissions or corrupt data.
- Tonal balancing across the entire orthoimagery.
- GSD ensures the specified resolution.
- No cloud cover, smoke/haze, and void areas.
- No extreme tonal or color variation across seamlines.
- No excessive horizontal displacement along seamlines (± 1.5 pixels along linear features).
- No ghosting effect in tall building/structure.
- No excessive tilt in bridges, buildings, and other raised features.
- No structure features obstructed and shadowed by buildings.
- Clipping of features (e.g. radio towers, water tanks, buildings) at tile boundaries.
- Sharp uniform balanced color contrast in mosaicking.
- Free of imagery smearing.

- Imagery artifacts appearing in the final orthoimagery are unacceptable, except for very minimal artifacts falling in noncritical coverage areas, e.g., a small piece of lint appearing in a timbered area.

4.2 **HORIZONTAL ACCURACY EVALUATION BY CHECK POINTS**

A number of check points should be used for evaluating the horizontal accuracy of orthoimagery. Check points will be independently surveyed with sufficient accuracy. The accuracy evaluation method will be comparison between the independently surveyed GCPs and the corresponding points on the orthoimagery. The geometric accuracy as per NSSDA reporting standards at 95% confidence level is defined as: Accuracy $r = 1.73 \times \text{RMSE}_r$, where RMSE_r is root mean square error in x and y coordinates at well defined check points (FGDC 1995; 1997). The limiting RMSE in x, y coordinates is 2' and 1' for [1"=200' and 1"=100'] scale, respectively. The RMSE errors are cumulative process errors including of ground surveys, map compilation and extraction of ground dimensions from the map.

4.3 **SHADOW RESTORATION**

The mean and the variance of the shadows restoration areas should be matching with the mean and the variance of an image with no shadows. The shadowed area should be substantially restored with high-quality and comparable to non-shadowed areas.

4.4 **OCCLUSION COMPENSATION**

Compensation rate of the occluded area should achieve over 98%. Missing compensation to the major ground features, such as manhole, fire station, bridge is not acceptable; expect the limited roadside occluded by trees.

5. ACCURACY

The accuracy of a digital orthoimagery is affected by several factors, such as photo scale, ground control, camera characteristics, DBM and DTM, etc. Therefore the producers of DOQs should ensure that all critical components have enough accuracy suitable for entering USGS orthoimagery.

5.1 GEOMETRIC ACCURACY OF ORTHOIMAGERY

The geometric accuracy of the high-resolution orthoimagery must have 95% (NSSDA Confidence Interval) of all well-defined points tested fall within $\pm 1.5 \times \text{GSD}$.

5.2 RADIOMETRIC ACCURACY OF ORTHOIMAGERY

Orthoimagery radiometric accuracy should have the same or better imagery equality as the original unrectified input images.

REFERENCES

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APPENDIX:

Basic procedure of orthoimagery generation

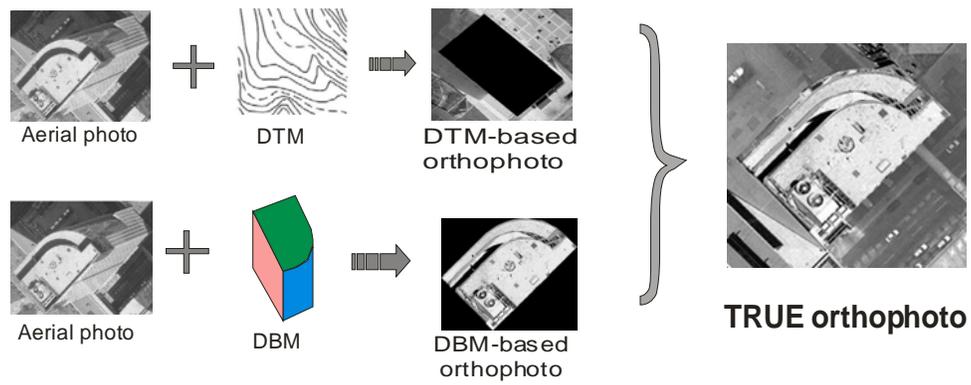


Figure 1. The procedure of true orthophoto generation