CONTROL PROCEDURE FOR TOPOGRAPHIC MAPDATABASE SETUP AND UPDATE

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ABSTRACT:

In this paper, strategies for development and evaluation of data control processes to database setup and update are discussed. Examples of production-workflow and control procedures used for the national topographic map-database of Denmark are presented. Map-objects to the database are collected and extracted photogrammetrically by subcontractors and controlled by in-house procedures. In the database setup phase data control was focused on data-specification, data-completeness and data–topology. Geometric accuracy was then controlled by large-scale photos in random test-areas. In the database update phase, efforts are now to ensure that all single map-objects are geometrically correct. The control software used has been extended to support highly accurate verification of map-object geometry, by Vector Transformation. The Vector Transformation methodology is build on fundamental equations of photogrammetry and is designed to work on PCs without stereoscopic view. It projects new vector data photogrammetrically on top of the unrectified image, accounting for inner orientation and rotation, by use of camera properties and already verified map-objects in X, Y and Z. The paper presents theory, workflow, features and experiences about Vector Transformation. To fulfill a need of verifying large areas of updates with little manpower, effort in making user interaction as automated and time saving as possible has been made. The paper points out elements in the workflow that are especially facilitated by automation. Experiences suggest that verification of map-data in 3D can be done with good results in a 2D environment, by a software solution offering functions as the presented.

1. INTRODUCTION

This paper deals with data quality and the need of elaborating the correct level of data control, at all times, through set up and updating of a database. To secure data quality and to define a control procedure in the case of database updates in general, one must be aware of both quality of data already in a database, and of data to update it. This points out the essential need for a continuous evaluation and knowledge of:

- Quality of data currently in the database
- Quality of data-source and of current data-collection
- Quality of data-extraction methodologies and of current data-extraction
- Quality and availability of both technology and manpower for data control

The overall data quality of a database, can not reach a better quality than the least satisfactory of these evaluation points described. Nevertheless, control procedures often give focus to the need of high quality data-collection and/or high quality data-extraction, giving little attention to data-quality of the database content and to quality of control procedures.

One goal of this paper is to point out the need for accepted long-term control procedures for database updates, and the need for a continuous evaluation of data control processes. The paper argues that, in respect of data quality, control should be neither “ad hoc assignments” nor “static processes”. Control procedure should be planned, with scheduled points of elaboration and optimization of the control processes. In addition, it is shown that focus on data-control does not necessarily result in more time and cost demanding workflows. It is pointed out though, that having continuous change in control procedures makes it difficult to ensure and describe the overall data-quality of a database.

The case presented in this paper, is part of the production workflow for the setup, update and control of the nationwide topographic map-database of Denmark. An overview of its data control processes, as part of the production workflow, will be given, with focus on the object-geometry control.

In the map-database setup phase the control process for geometric accuracy was in two dimensions, which was extended to include the third dimension in the database update phase. Object geometries are extracted from aerial photos in 3D by photogrammetric methods. A methodology for control of objects geometries with 3D accuracy in a 2D environment is presented, and results and gains from implementing this methodology is described.

2. DATABASE SETUP, UPDATE AND CONTROL

The Danish national topographic map-database in 1:10000 is named TOP10DK (Frederiksen et. al., 2004). It was designed in the 1990’s and in 1995 data from the first part of Denmark was put in the database and since 2000 TOP10DK covers all Denmark. The map-database is owned, maintained and distributed by National Survey and Cadastre – Denmark (KMS).

An overview of improvements in data-control flow through the production period of the TOP10DK will be described according to the four evaluation points described in the introduction. This is aerial photographing as the “data-collection” process, stereoscopic object extraction as “data-extraction” and in-house developed and performed processes for “data-control”. Different assumptions according to the setup or update production phases are also pointed out.

2.1 Data-collection workflow

The data-source for TOP10DK was B/W aerial photos in the setup phase until 2000, and since then color photos - both in 1:25000. Photos are collected with 60% length overlap and 20% side overlap to allow a stereoscopic data-extraction process. Photographing occurs from March through May when Denmark is no longer covered by snow and the trees are not in leaf. Data-collection covers approximately 1/5 of Denmark every year. It is done by subcontractors after detailed specifications (KMS, 2004a).

When weather and sun/light conditions are satisfactory, the aerial photos are collected from a given flying height at specified geographical coordinates given by KMS. Since year 2000, the aerial photos are scanned in 21-25 micron as specified (KMS, 2004a), allowing data handling from then on to be done digitally. Contractors are responsible for film exposure, development and scanning and therefore for the end-quality of data to be used for the object extraction. Contact copies, dia-positives and enlargements were produced up till 2004, but future data-extraction and control will be pure digital.

2.2 Data-extraction workflow

Extracting data or objects from the photos, is done on photogrammetric workstations by subcontractors. In the database setup phase, contractors received film material and other necessary data for the aerial triangulation (camera calibration, GCP's etc.). The established photogrammetric parameters (tie-point coordinates, sketches etc.) were then returned to KMS together with the extracted objects.

For the database update phase, subcontractors receive both new digital photos (images) and the aerial triangulation parameters originating from the first data production in that area - to be able to set up the exact same aerial triangulation for the new images.

Map-objects are extracted, in all tree dimensions, according to rules specified in an object specification (KMS, 2004b). A new updated digital version of the object specification is scheduled for every years production – as changes in the object rules are still in progress. Object-updates must take into account, both changes derived from renewed specification rules as well as physical changes in objects. Physical changes, i.e. new, changed or erased objects, when compared to the current database content. For this purpose, contractors receive all existing objects in their area from the database, allowing them to impose vector data to the images.

2.3 Data-control procedure

A number of control processes are implemented in the production flow. They are developed in different stages of the database setup and the database update phases - and for different needs. Most of them are incorporated in Mapcheck, which is an in-house developed control- / GIS- software used by both KMS and the subcontractors. Other control processes are executed in other surroundings or performed manually.

2.3.1 Control of photos – The data-collection workflow includes different control processes. These processes are to ensure that data is adapted with sufficient good quality for the map-object extraction. The control processes, which are all performed by in-house employees, treat subjects as:

- Automatic mathematical control of photo-point accuracy and overlap between neighboring photos (by exposure GPS coordinates according to photo-points as specified)
- Visual control of developed film for visibility, color and coverage (clouds or shadows) and photographic end-products for visual appearance
- Random check of scanned images. Visually control for color balance, hot spots etc. and automatically control for color distribution (both since 2002).

2.3.2 Control of objects. The data-extraction workflow also includes different control processes. These are adapted to ensure that objects are collected according to specifications, and keep the specified geometric accuracy. The control processes are performed by in-house employees and treats the following subjects.

- In the **database** and **aerial triangulation setup phase**, independent control of the geometric accuracy was performed by large-scale photos in 1:5000 in test sample areas. In these photos selected objects were measured at photogrammetric workstations and compared to the extracted data from 1:25000 photos, for statistical judgment.

- In the **database setup and update phases** control did and still does concern topics such as:
  - Topology in data, is evaluated by function that automatically check if all vectors are connected as specified
  - Individual objects extracted according to specifications. Are checked by functions that automatically measure/calculate object "values" and compare these to specification values
  - Data completeness and geometry is checked by manual control. Objects are compared visually with their appearance in an image on a PC consol. Control is carried out on polynomial rectified images, with low correlation away from the photo-center

Because all production is done by different subcontractors, the control procedure is taken into evaluation for every production block.

2.4 Evaluation of control procedure

During development and production of TOP10DK, all control processes have been in focus and adjusted. Because TOP10DK is not of a predefined design, it is an ongoing job to develop both specifications and the control routines, according to current production-workflow and the current data quality.

2.4.1 Evaluating, control processes. From the current state of data in the database and the existing control procedures referred in 2.3, ithas been possible to identify the following list of areas where suggestions for the control processes or the workflow, would add value to the data quality.

Photo control processes, possible improvements:

- ***Concerning***: Automated control of photo-center accuracy and overlap between neighboring photos.
  Suggestion: It is evident that GPS has already minimized the number of photo-center errors. Use of INS/IMU could improve positioning even more and allow less attention to the photo-center control
- ***Concerning***: Visual control of the appearance of photographic end-products. The production line from 2004 will no longer include photographic end-products. But the in-house control procedures still demand contact copies, to compensate for loss in detail in the scanned images of 21 micron.
  Suggestion: Need for contact copies disappear with a better scan solution or by usages of digital cameras
- ***Concerning:*** Manual random check of scanned images.
  Suggestion: Automatic control of all images should be implemented. Future use of digital cameras might make control of scanned images unnecessary

Object control processes, possible improvements:

- ***Concerning****:* Control of object geometry is currently in 2D, by polynomial rectified photos
  Suggestion: Controlling all objects in all three dimensions is essential, and can be solved by:
  - Use of photogrammetric transformation of vector data (X, Y, Z) into raw image
  - Use of orthophotos
- ***Concerning:*** Control of object data according to specifications, is currently by "hard-coded" routines.
  Suggestion: Specification rules should be archived and accessed in a database. This would also make it possible to control object data according to their setup specification
- ***Concerning:*** Current control of data completeness is performed visually by polynomial rectified images.
  Suggestion: Automatic change detection or identical accuracy and better correlation all around the image, between image-objects and vector-objects is essential - and can be solved by:
  - Use of photogrammetric transformation of vector data (X, Y, Z) into raw image
  - Use of orthophotos.
  - Automatic detection and classification of objects / changes in a image (Olsen, 2004)

2.4.2 Optimizing, control processes. It was recognized from this evaluation process (2003), that object-geometry control did have highest priority for development. A tool for photogrammetric transformation of vector data to raw image was therefore decided, as a new control procedure.

3. CONTROL OF 3D-DATA IN 2D-ENVIRONMENT

To illustrate the continuous development of the control procedure used for TOP10DK, the chronicle steps of optimizing object-geometry control are listed:

- In the database setup phase: random checks in 3D
- Overall 2D-control by polynomial rectified images
- In the database update phase: overall 3D control, by photogrammetric transformation of objects (X, Y, Z) into the raw image

3.1 Photogrammetric transformation of vector data

The developed method for photogrammetric transformation of vector data is called the "Vector Transformation" module (VT module). It is implemented by approved photogrammetric methodologies but is for practical and economical reasons designed to work on PCs without stereoscopic view. The VT module projects the vector data photogrammetrically on top of the raw image, accounting for camera properties and map-object coordinates (X, Y, Z).

The goal of the method is to develop a tool for the control of geometric accuracy of individual map-objects in 3D so that:

- Map-objects that are registered correctly in X, Y and Z – will be displayed (draped) exactly on top of their appearances in the raw image (as good as the photogrammetric parameters allows).
- The accuracy of the draping will be the same in the whole image, meaning no need of shifting vector data in the image periphery to match their appearances (as is needed for polynomial rectified images – fig.4).
- When single map-objects are displaced from their position in the image, something is wrong in that specific object.
- When all map-objects are displaced from their position in the image, some fundamental error has occurred. Error can be from the VT-parameter-calculation or from the model orientation used by contractors for the object extraction. Both can and must be checked.

Integrating the technique into production in KMS was done with guidance from a research-project of the methodology done by Jon C. Olsen (KMS). Functions were integrated in the production and control software Mapcheck, and facilitated with automation features.

3.2 Vector Transformation methodology

The Vector Transformation module is built on the fundamental equations of photogrammetry. Parameters for the transformation are calculated through the knowledge of inner orientation (IO) and rotation (D) of the image. Stating that coherence between vector map-objects in geographical coordinates and their coordinates in image pixels, are calculated for each image, by information about:

- Camera calibration
- Fiducial coordinates
- A number of well distributed ground control points.

The inner orientation is found through an affin transformation of the six variables, for the coherence between fiducials measured in image and data from the camera calibration, solved with a least square calculation.

The rotation matrix (D) is evaluated by :

$$D\,X' = M\,(X-X_0)$$
$$D\,Y' = M\,(Y-Y_0)$$
$$D\,-c = M\,(Z-Z_0)$$

Where: $M = \dfrac{c}{h}$

$h = (Z_0-Z)$

and:

- X_0, Y_0 and Z_0 are image center coordinates
- c is camera constant (mm)
- X, Y, Z are known coordinates for a number of objects well distributed in the image.
- X', Y' are measured image coordinates for the same ground control points.

which gives:

$$D\,X' = -c(X-X_0)/(Z-Z_0) \quad (1)$$
$$D\,Y' = -c(Y-Y_0)/(Z-Z_0) \quad (2)$$
$$D\,{-c} = -c$$

The rotation matrix D is then solved from (1) and (2) by use of a number of ground control points (GCP's as X, Y and Z) measured in TOP10DK and in the image at their image-location (X', Y'), and the previous solved IO. When the rotation matrix for the image is determined, any map vector point (objects) with known X, Y, and Z, can then be transformed backwards through (1) and (2) to their position in the raw image.

3.3 VT, rectification workflow.

The VT technique implementation in Mapcheck is presented as part of the production/control workflow for updating TOP10DK.

3.3.1 First step - measuring ground control points – to determine rotation matrix by 1) and 2). KMS receives update-data from contractors in blocks each covering a photogrammetric model. A update-data model must be controlled geometrically with images rectified by already verified TOP10DK data - any of the two model-photos can be used. TOP10DK data from the database are therefore used for the GCP measurements (automatically extracted according to the chosen photo's GPS photo-center).

This is shown in fig. 1. There is no exact fit between the already verified vector data and the new images, though it is possible to recognize corresponding objects. Enough well distributed ground control points (GCP's) must be measured (selected with point snap) as TOP10DK database data (fig.1, Yellow crosses) and then connected to its corresponding pixel in the image (fig.1, Yellow vectors).

To support the operator in this GCP-process, the vector data are shifted and turned immediately, when the user generates the first and the second ground control points, this makes it a lot easier to locate the following points. Qualified suggestions for ground control points, can be demanded to be automatically presented to the operator, in a reasonable zoom, for manual connection to its corresponding pixel.

To evaluate coherence and accuracy of the measured points, the root mean square is calculated and reported to allow the user to accept the calculation errors and the final point distribution by visual judgment, or to measure more points.

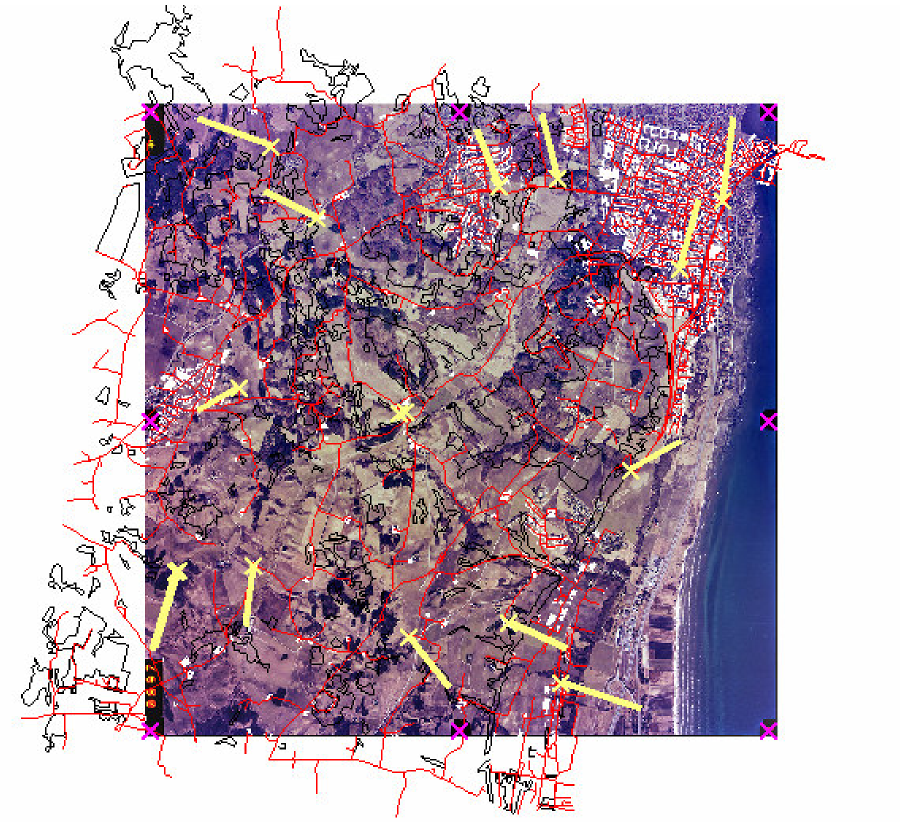

Figure 1. Initial rectification measurement for Vector Transformation. Red crosses are measured fiducials. Yellow crosses are the ground-control-points as vector-object and the yellow connection vectors are pointed to corresponding G.C.P. image pixel. Height differences (Z) between GCP's are about 100 meters

3.3.2 Second step - reading camera calibration and measuring fiducials – to determine IO. Camera calibration parameters are stored in the database and by connecting the image to its corresponding camera calibration, the user must measure pixel coordinates for all fiducials found in the image (fig.1, red crosses). To facilitate the manual measurement, Mapcheck pans and zooms in, close to the image location of the fiducials – one by one. Then the operator only has to point out its exact image pixel location.

3.3.3 Third step – verification of image rectification and archiving metadata. It is possible to verify the precision of the VT parameters (IO and rotation) calculated for an image, by draping the database vector data as was used for image rectification. This makes it possible to judge, if points are measured correctly. When ground control points and fiducials are accepted, metadata is put in the database.

3.4 VT Control procedure examples

To illustrate different aspects of the implemented VT methodology, examples are presented and discussed next:

3.4.1 Image-overview and -loading. With model vector data loaded as a map in Mapcheck, it is possible to get a visualization of all images that are ready for VT module prepared, and cover all or part of the model (fig.2).

From this, one can choose the best image offering best coverage of the current model. When "right clicking" with the mouse, it is possible to load that raw image, having its photo center closest to the mouse cursor position (fig.2). It is possible to toggle between all raw images that are ready for VT presentation in this way. Loading a raw image with vector data on top, only takes a few seconds.

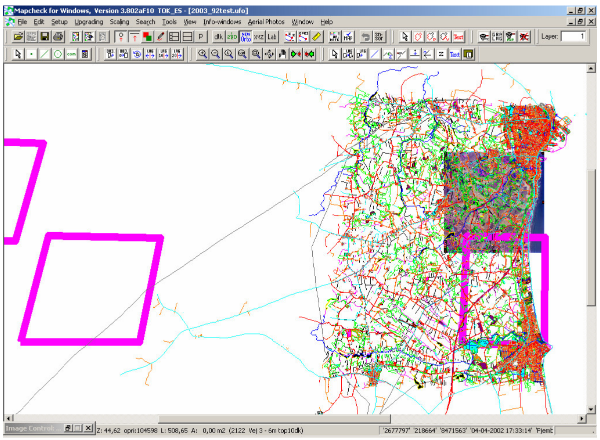

Figure 2. Shown is a block of update-data to be controlled - together with the images, ready for photogrammetric transformation of vector data (X, Y, Z) in that area. Image-coverage are shown with red lines. These are shown photogrammetrically, from the photocenter of the active photo

3.4.2 Single object error. Having vectordata active and loading a raw image in VT mode, the vector data are draped on the image as defined in the photogrammetrical metadata stored in the database (calculated IO and D, as in 3.3, from all ready verified TOP10DK objects).

As shown in fig.3, the VT module gives a very high correlation between vector data and the raw image, and most objects are matched exactly to their appearances. Vector data is at their positions even when they are not straight lines because the photogrammetric displacement is adapted. It can be seen that when a object is digitized with a wrong Z coordinate, then the vector-object will be shown displaced away from its correct image-position (fig.3, a small building at top). The height of that displaced building object is measured as 0 meters, where as the correct building height should be around 70 meters asl.

3.4.3 Systematic object errors. When displacements are general in a model, the reasons could be failures in parameters for the photogrammetric transformation of vector data or it could be systematic error concerning the image-orientations (AT setup) used by contractors. VT-rectification parameter errors can be checked by using neighboring images covering the same area or alternatively using independent ground control points for the calculation.

Systematic errors due to errors in the original image-orientation (AT) could be hard to recognize in this workflow, because data from the database, might include errors, is used for calculating the rectification parameters. If there is any doubt about the database data-quality, then control has to be done by use of independent ground control points.

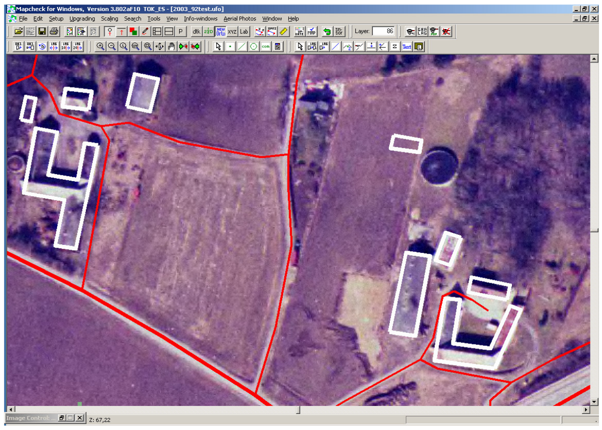

Figure 3. Example of Vector Transformation on raw image. The vector building shown close to silo has wrong Z value (0 m should be 72 m), and is displaced from its correct position by the road.

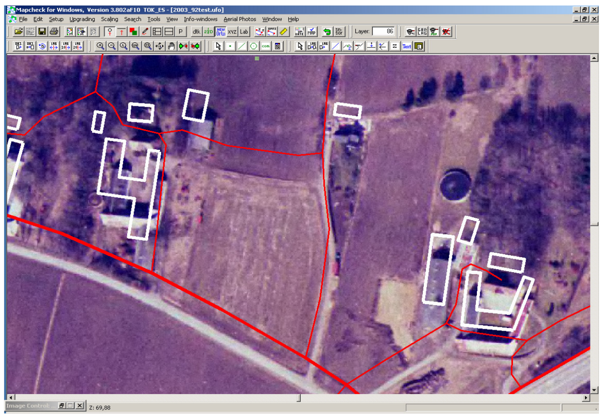

Figure 4. Same area as shown in fig. 3, from the polynomial rectified image (same fiducial and GCP's). Big displacements.

3.4.4 Vector Transmission compared to polynomial rectified image. An example of Vector Transformation is shown in fig.3 for a rural area in Denmark with height-level differences up to 100 meters in that image. The area shown is far from the image center and close to the corner fiducials. The same area is shown in fig.4 – but here from a polynomial rectified image (same GCP's as used for the VT calculationl). It is obvious that Vector Transmission is showing a much better fit to objects in the image.

3.4.5 Vector Transformation misalignments. Due to the nature of the transformation, it is not possible to measure exact values of the displayed vector data (lengths, areas, angels etc.) because vector points are individually displaced.

Another problem to be treated is when object types have different height specifications. Some object types are measured at object bottom (roads, rivers etc.) and some are measured at the top of the object (trees, buildings etc.). If two objects of different height specification (bottom/top) are from the same geographical coordinates (X, Y), then VT methodology will show the two at a distance to each other, because their height is used for calculating their location in the image. An example is shown in fig 5 (top) where road and forest border are crossing each other.

To overcome this problem, a function has been implemented where Vector Transformation is calculated by using height values from a DTM (already present in Mapheck) instead of using the object heights. This means that object vectors are "straightened" out, but also that objects are displaced from their original position in the image (fig.5 bottom).

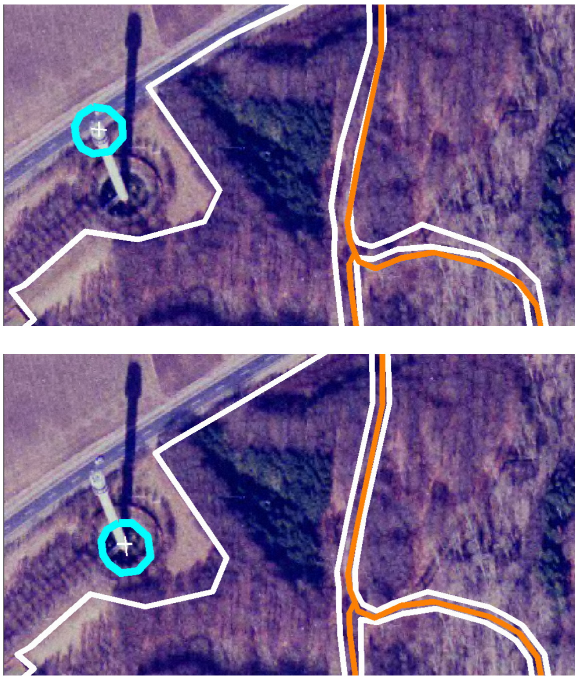

Figure 5. ***Top:*** **Displaced objects caused by different object height specifications – by Vector Transformation (white trees in top and orange roads at bottom).**
Bottom: **VT with objects relatively straightened out, using height data from DTM**
Top + Bottom: **Notice cross on "top" of the pipe (in blue circle)**

3.4.6 Vector transformation, automation. To meet the needs for expanding the control of geometry to 3D and still verify large update-areas with little cost and manpower, an effort in automating the system has been made. Some semi-automatic procedures are to be mentioned.

Suggestions and automatic zoom are given for the:

- Placement of fiducials, to be used for IO
- Placement of visually good building corners (no shadow or trees) with good distribution in the image (GCP's), to be used for calculation of the rotation matrix

Other facilities in the VT rectification workflow are automatic extraction of TOP10DK data from the database, covering raw images that are loaded to be rectified (area is calculated from image GPS-center and image-size). In the rectification workflow, there is also automatic adjustment of vector-data when ground control points are measured.

4 SUMMARY AND CONCLUSION

Experience has shown that control of object geometry can be done with good results in 3D using mono environments, by a software solution with photogrammetric functions as shown.

The Vector Transformation module shows potential for further development to manage object measurement and database updates from the 2D environment. It is planned to develop a system to use measurements of object pixel coordinates directly in a raw image in VT mode. Transformation of the object-pixel-coordinates to UTM should then be by the VT methodology, using the DTM-height in addition with a "surface-element-height" given by the operator.

It is argued that data will gain in quality by control procedure evaluation in a scheduled plan – also taking into account the current and end-goal quality of the database content.

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