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PHOTOGRAMMETRY AND MONITORING

A test using historical aerial photos for 3D change detections of a cultural environment

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Sammendrag

This report presents the result of a short test with the aim of conducting a 3D change detection based on aerial photos kept in archives and a recent LiDAR data set. Change detection ois a vital part of any monitoring project. Archaeological sites, monuments, environments and landscapes are vulnerable and often exposed to unwanted changes. Monitoring is a way to observe and measure changes which may occur over time. The purpose of cultural heritage monitoring is typically to detect actual changes occurring or to establish early warning systems using indicators in order to be able to take actions to prevent an unwanted development. The pebble stone grave field at Mølen, Larvik municipality in Vestfold county municipality was chosen as a case study area. After a short section presenting state of the art on this subject the methodological approach used in the study is described in detail. Most of the effort was concentrated on scanning and digitalizing aerial photos from 1979 a task that turned out to be more complicated and time consuming than expected. Unfortunately the model generated from the 1979 photos was not applicable for change detection which means that the last goal was not fulfilled in the test. Nevertheless the results of the study are promising, and some positive outcomes have been demonstrated which makes us recommend a continuation of research and development of 3D change detections.

Emneord

Monitoring, 3D images, photogrammetry, LiDAR, automated change detection, cultural heritage, heritage site

Avdelingsleder

Kari Charlotte Larsen

Forord

In 2011 NIKU –the Norwegian Institute for Cultural Heritage Research- received financial support from The Directorate for Cultural Heritage in Norway, equivalent to a week's work, in order to conduct a test using historical aerial photos and LiDAR data for 3D change detection of a historic site. In addition NIKU used internal funding in the accomplishment of the test. The present report documents how the project was carried out and the first results obtained. The technical implementation turned out to be more complex and time-consuming than supposed initially. Many variables related to the historical material affected the test, thus not allowing us to carry through all steps of the study within the available time and financial frame. Nonetheless, the obtained results are significantly important and create a basis for further research and development into the issue of combining historical aerial photos and LiDAR. The project has contributed to the increased competence on a potential new use of a large and valuable source – such as the huge amount of aerial photos kept in archives. We would like to thank the Directorate for Cultural Heritage in Norway for financial support and Menci Software for their professional support and for letting us use a trial version of their software.

Contents

1 Background

1.1 The project

Archaeological sites, monuments, environments and landscapes are vulnerable and often exposed to unwanted changes. Monitoring is a way to observe and measure changes which may occur over time. The purpose of cultural heritage monitoring is typically to detect actual changes occurring or to establish early warning systems using indicators in order to be able to take actions to prevent an unwanted development. Methodologically this is currently done by conventional field-work or by the use of aerial photos or satellite images. Further some projects have been carried out in recent years in order to test how LiDAR[1] as a remote sensing technique can contribute to establish efficient monitoring systems to estimate and control unintended loss and changes to valuable cultural sites and monuments.

[fig.1] Map of Norway. The area of study lies on the South coast of the Country. ©GoogleMaps

Since 2005 NIKU has carried out a series of LiDAR projects with financial support from i.a. the Directorate of Cultural Heritage. These projects have focused on detection and documentation of cultural remains in forested areas (Risbøl et al. 2006, Risbøl 2009, 2010) but in recent years this research and development effort has also included the use of LiDAR for monitoring purposes (Barlindhaug et al. 2008, Risbøl and Amundsen 2011). LiDAR has proved to be an effective tool for documenting large areas and represent a potential cost-effective method for monitoring cultural heritage.

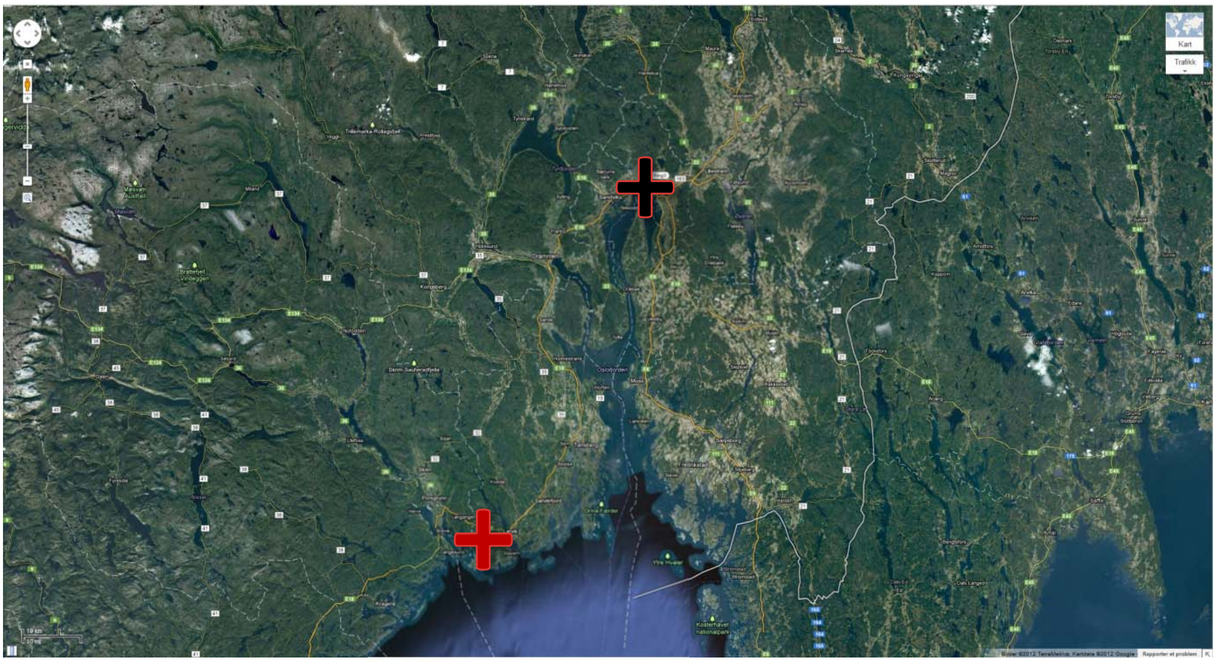
One successful approach to monitoring we have tested is the use of two LiDAR data sets as a basis for automated change detections, which has proven to hold a potential as a method for time-saving monitoring of large areas. In addition automated change detection probably also provide results with larger objectivity compared to analyses of landscape changes based purely on visual studies. In a

[1] LiDAR = light detection and ranging or airborne laser scanning.

hitherto unpublished study we ran a series of automated change detection with LiDAR datasets from 2008 and 2010 respectively by the use of a basic LiDAR visualisation and analysing software called *Quick Terrain Modeler*. These initial tests gave promising results indicating a great potential of using LiDAR datasets for monitoring purposes that necessarily needs further investigation and development. The present study builds on the results and experiences of previous monitoring studies at NIKU. The study focuses on how it is possible to compare different 3D models generated through photogrammetry of historical aerial photos in combination with LiDAR generated digital terrain models.

LiDAR is a quite new technique with a relatively short history – especially with reference to its application to cultural heritage where the use only goes back a little more than a decade. This is a limiting factor if we want to carry out 3D based automated change detections of longer periods and the time prior to the introduction of LiDAR. Thus the main reason for initiating the current study was to test if it is possible to generate a 3D dataset based on photogrammetry using existing historical aerial photos and then use this dataset to conduct automated change detection where it is compared to a LiDAR data set collected recently. By this approach we anticipate that it should be possible to automatically detect changes that have occurred in the landscape studied in the period of time between the taking of the aerial photos and the time of the laser scanning.

In order to conduct the test we chose the grave field at Mølen in Vestfold County as our study area. Mølen [fig.2] was chosen because it is a highly valued Norwegian site with Iron Age pebble stone grave cairns which in addition is a popular but vulnerable site with many visitors due to its natural and cultural amenities. Therefore changes can be expected to occur quite rapidly. These facts make the site appropriate as a case-study area. Also, LiDAR data from 2008 and 2010 as well as a series of aerial orthophotos (digitalized) from Mølen that was used for a retrospective aerial photo study covering the last 50 years (Risbøl & Nesbakken 2009) was at our possession. Together all of these variables make Mølen a suitable case study area.



[fig.2]
The area of study -Mølen- is located at 150 km South-West of Oslo, Norway. ©GoogleMaps

1.2 State of the art

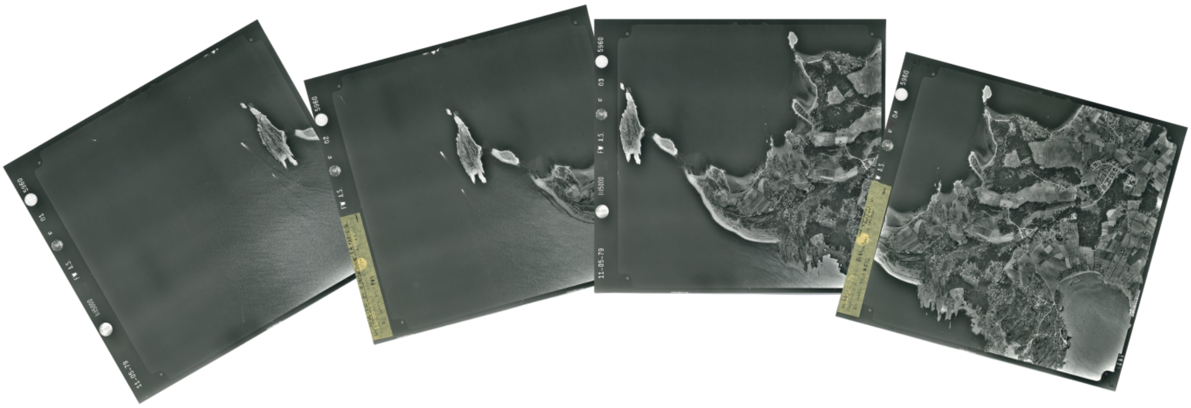
The potential use of LiDAR for environmental monitoring purposes within the management of cultural heritage is mentioned by for instance Barnes 2003 and Barlindhaug et al. 2008, but there are few examples of actual use (Risbøl and Nesbakken 2009, Kincey and Challis 2010, Risbøl and Amundsen 2011). It seems though that LiDAR has been more widely used for surveillance in other disciplines. This is for instance the case in documentation and monitoring of erosion and other sediment dynamics along coasts and shorelines (Stockdon et al. 2002, Robertson et al. 2004, Deronde et al. 2008). Undoubtedly LiDAR will develop to play a future role in monitoring of cultural heritage due to the advantages of working with 3D data and also due to the general application of LiDAR for all kinds of mapping purposes.

Over the past decades, Norway has been mapped a number of times by the use of aerial photo documentation. This means that by utilizing a series of photograms using a precise flight plan it should be possible to create a 3D model of a section of a landscape as it appeared at the time of shooting. Instead of utilizing a manual stereoscopic approach, even on a digital platform, it appears fundamental to investigate if a software can be used to produce a 3D model detailed enough for cultural heritage analysis. In this case, multiple images can be analyzed together, thus creating a network of stratified information framing a DEM[2]. The "historical-DEM" can be theoretically compared against a 3D model generated by a contemporary LiDAR dataset. As LiDAR has proved its ability in comparing multiple datasets, revealing differences and changes, it appears as a useful tool to assess areas of cultural interest which are subjected to for instance hazards. Subsequently the interpretation of the detected changes should be developed, in order to acknowledge the nature of the change within the particular landscape under study.

Generating a 3D model through the combination of image and range data is possible (Lambers et al. 2006). This means that a combination of information gained from point clouds and photos can be used to make an efficient record of archaeological sites and the state of these. The combination of digital photogrammetry and LiDAR allow archaeological sites to be recorded efficiently and in detail. Multiple datasets, from diverse time periods, could then be linked together, thus allowing cultural heritage analysis at multiple scales. The main idea being the possibility to overcome the individual weakness of each technique through their combined use, exploiting their complementary nature.

Studies are being carried out by a number of researchers, on the possibility of improving the association of an analogic dataset to a 3D model. In this sense, research is being conducted in order to improve the performances of matching technique in order to generate dense point clouds from images (Nex et al. 2008; Verhoeven 2011).

[2] DEM = digital elevation model



[fig. 3]
“Vestfold 5960” series. According to the flight plan, from left: F01, F02, F03, F04.

2 Method

The main idea behind this study was to generate point clouds from image triplets, starting from a set of aerial pictures from 1979. Four subsequent images were chosen, in order to perform this study. The area of interest is Mølen which has been portrayed on multiple historical photograms, thus enabling an evaluation not only of the bi-dimensional data [x,y] but also the third dimension [z].

The software *Z-Map Z-Map Foto* 4.2.6.0 was used to perform a preliminary study and analyses. Menci Software -*Z-Map* software owner- agreed on assisting towards the delicate calibration of historical aerial datasets from 1979 into the *Z-Map Z-Map Foto* data space. A semi-automated technique was used, as *Z-Map* is a human-interactive software.

The applied methodology followed these steps:

a. scanning of the photographic material from the 1979 flight
b. transformation of the scanned data into a digital image
c. creation of a certificate for the camera -camera passport- that holds the camera and the lens features
d. generation of the internal orientation of the raster data
e. identification of the control points
f. generation of the external orientation

The fact that it was possible only to access analogic paper-printed photos represented a challenge. In fact, not only the quantity of information the software can utilize is reduced compared to the original film or to a contemporary digital image. Moreover, the quality of the acquiring hardware - the camera itself - amplified the noise on the information. Significant areas may present an overexposure, thus preventing the software to correctly iterate the analyses need to create a DEM. In addition the presence of handwritten marks on the photos also caused “black spots” of data information. We still wanted to test the possibilities from using such data, as this will often be the best, sometimes the only, visual data available for retrospective analysis of this kind.

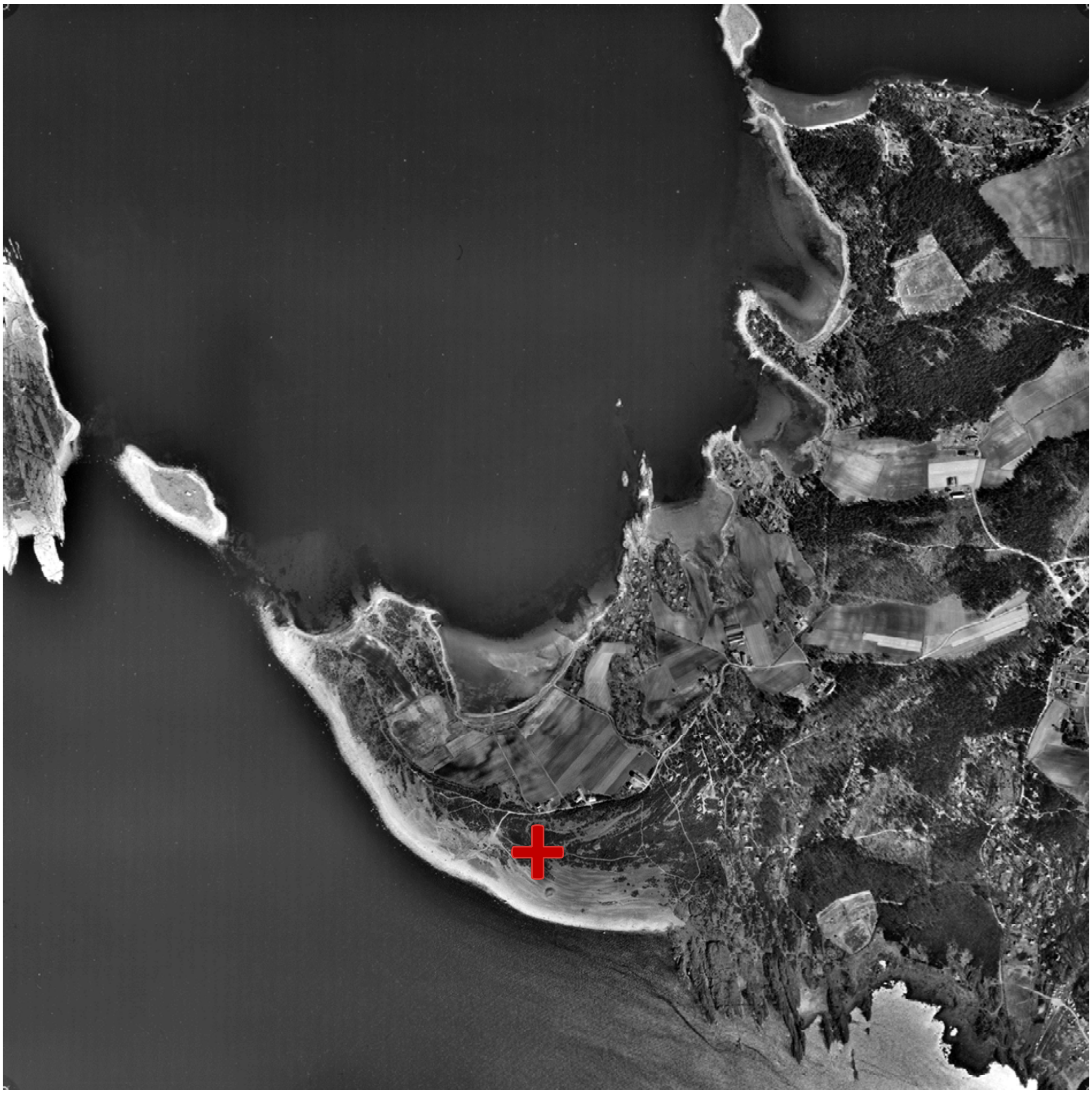
2.1 Scanning the photographic material

Four images, belonging to the series “Vestfold 5960” F01, F02, F03, F04 [fig. 3], were scanned. An Epson Perfection V750 PRO was used, with a 16-bit Grayscale at 2400 dpi maximum resolution.

Being the original data on paper support, this means an 8-bit type would have been sufficient. A 16-bit would be definitively the best choice if the original film could be acquired via scanner. It is recommended to acquire the data through a non-commercial hardware, specific for this purpose.

2.2 Scanned data becomes a digital image

The next step was to create digital images from the scanned pictures. To do so the fiducial marks on the photos were used, since the data derives from an analogic camera. By international protocol it is assumed that the fiducial marks are located on the perimeter of the image, with 90° angle between each-other at the same distance from the centre of projection. Being the photographs scanned, they presented a distance of 20050x19900 pixels. It has been necessary to create a warping rectangle, assigning the final length of 20000x20000 pixels between each fiducial mark [fig. 4]. The photo F01 was excluded both because it does not overlap on the area of interest and because more than 75 % of the area was water and thus impossible to use for the purpose of the study.

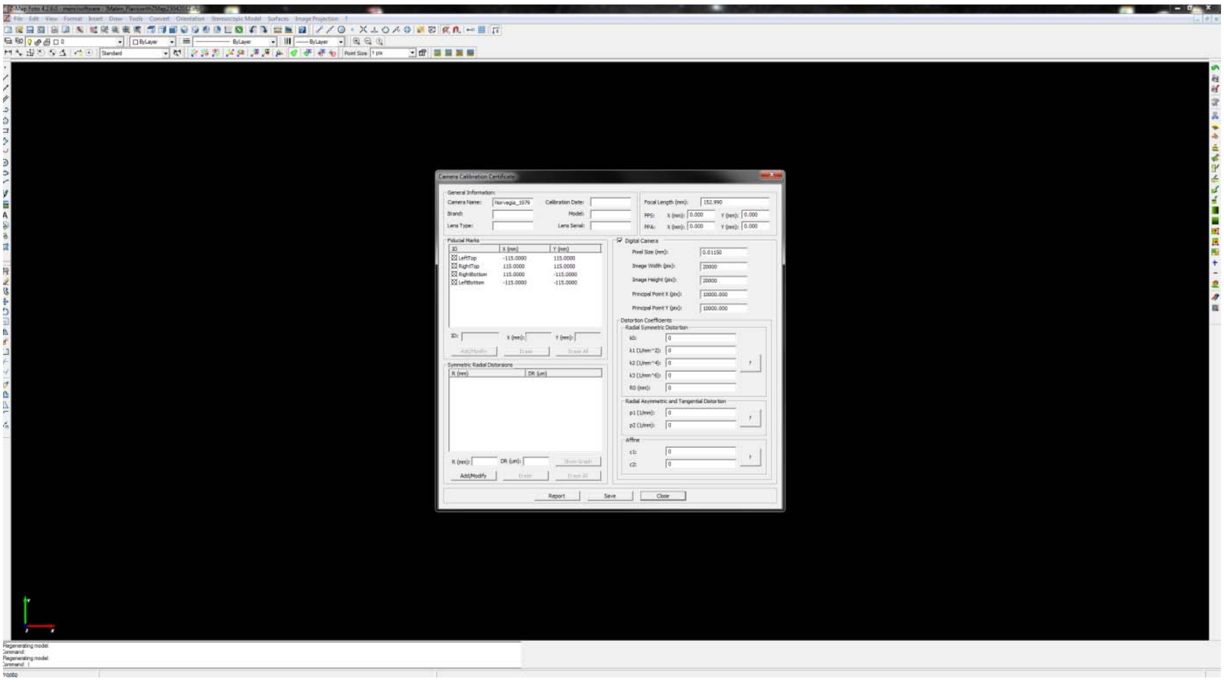


[fig. 4]
"Vestfold 5960" series, F03. The area of study lies along the shore and partially on the peninsula.
The four corners of the image correspond to the centre of the fiducial marks. Three photos present significant overlapping.

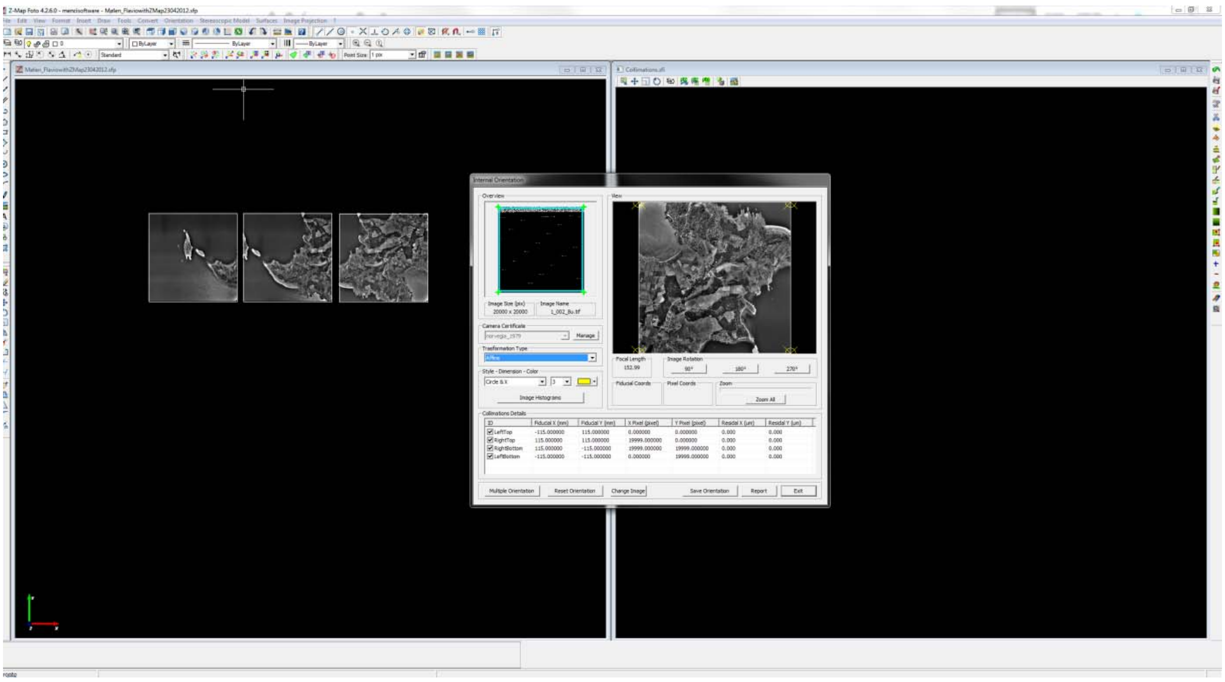
2.3 Camera passport and internal orientation

The camera certificate [fig. 5] - or camera passport - is needed to generate the internal orientation. This is necessary in order to describe the image geometry. The internal orientation [fig. 6] is therefore a transformation from pixels to fiducial coordinate systems [Menci Software, 2008].

This certificate reports the camera features. Since the photos were obtained from an analogic camera, the fiducial marks were collimated and assigned to known coordinates, through the certificate itself.



[fig. 5]
The camera certificate assigns a precise coordinate system to each and every single fiducial mark.



[fig. 6]
The Internal Orientation describes the image geometry.

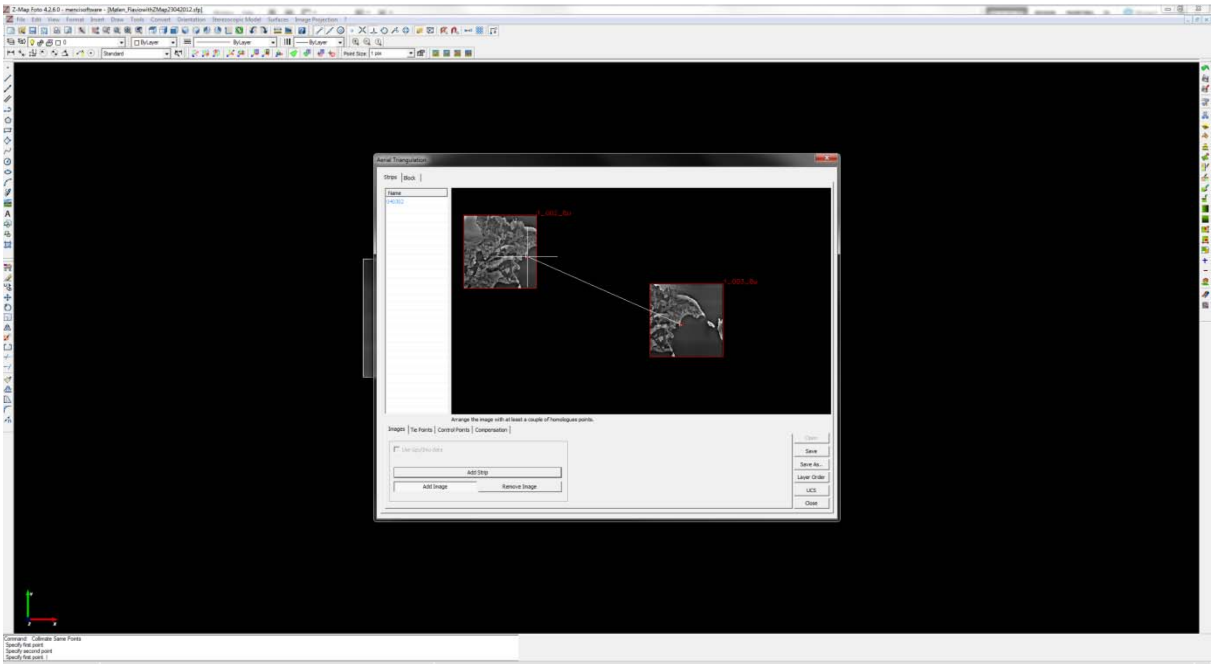
2.4 Control points and generation of external orientation

Once the images [*.tiff] were imported into the project, they have been mounted according to the original flight plan. When all the data was correctly placed, the external orientation had been performed. This means that it is possible to describe the spatial position of the projection centre of an image. This is done via 3D coordinates [x, y, z] and three rotational angles [W,f,k].

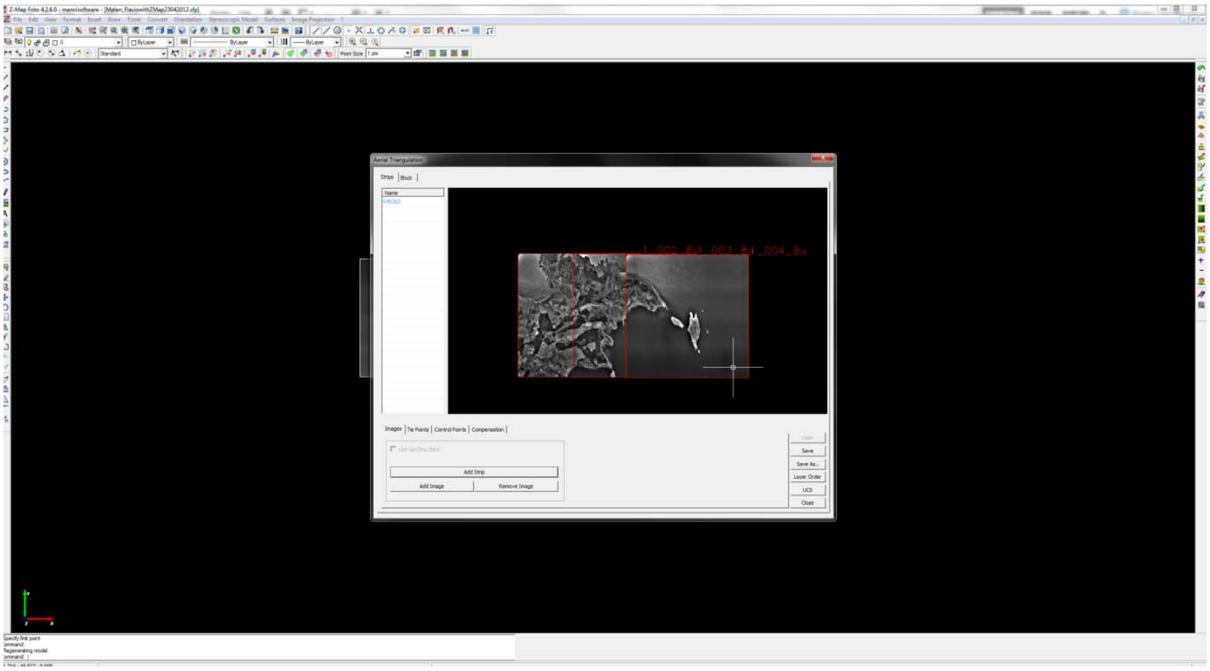
Z-Map Z-Map Foto allows for using different types of algorithms to obtain these six parameters where the choice of which to use depends on the goals of the study.

In this case both the aerial triangulation and a relative/absolute tool were considered.

The aerial triangulation was taken in consideration as first choice, being able to work on a strip of images: F02, F03 and F04. In fact it is a methodology used to get external orientations of more than one couple of images [fig. 7, 8].



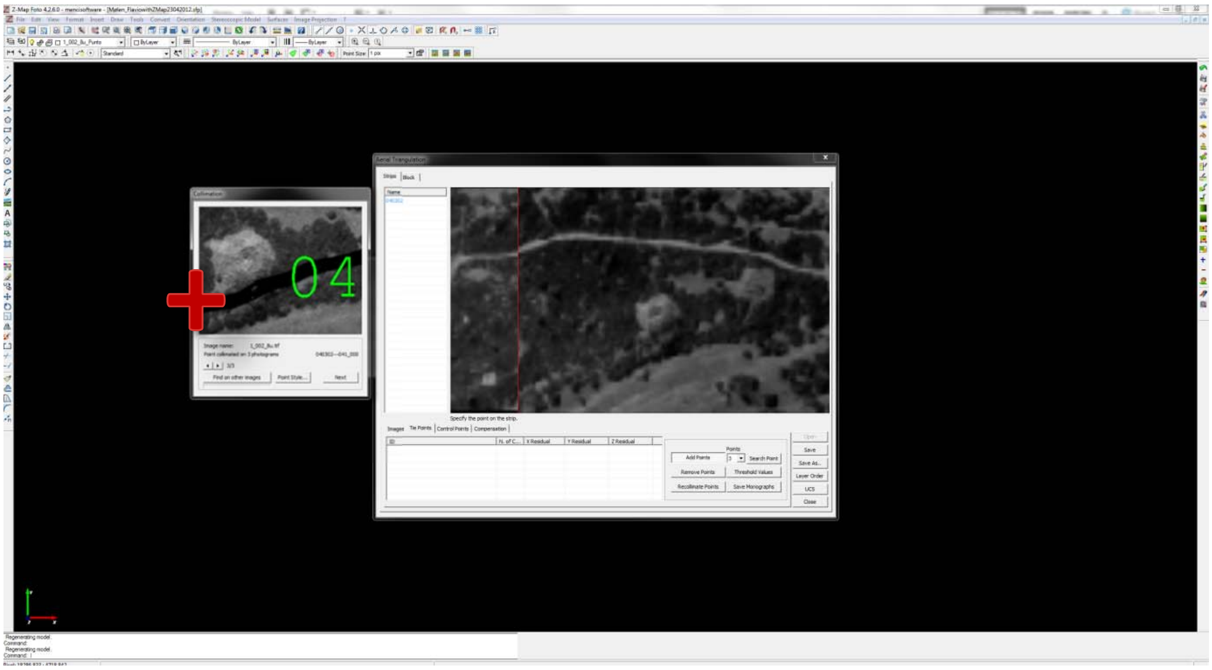
[fig. 7]



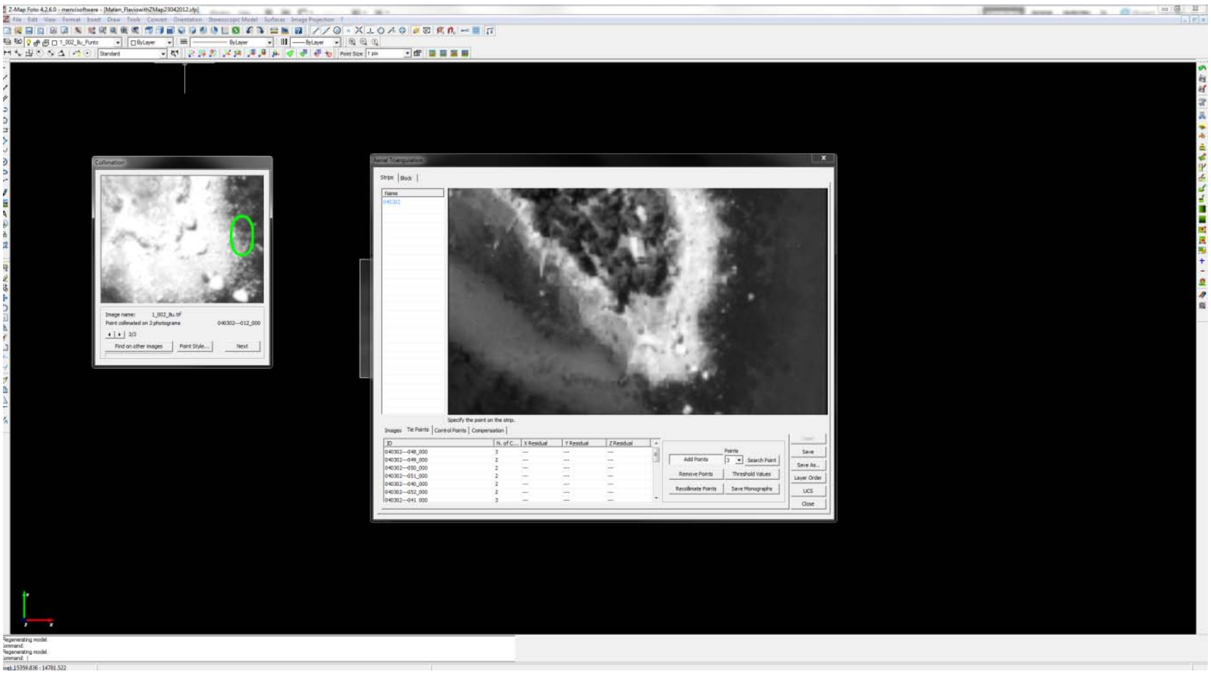
[fig. 8]
Mounted strip.

As a next step the tie points were identified, well distributed on the pictures and especially on the overlapping areas. In some cases some damages were recognised within the original printed picture itself. For example pen marks [fig. 9] or overexposed parts [fig. 10].

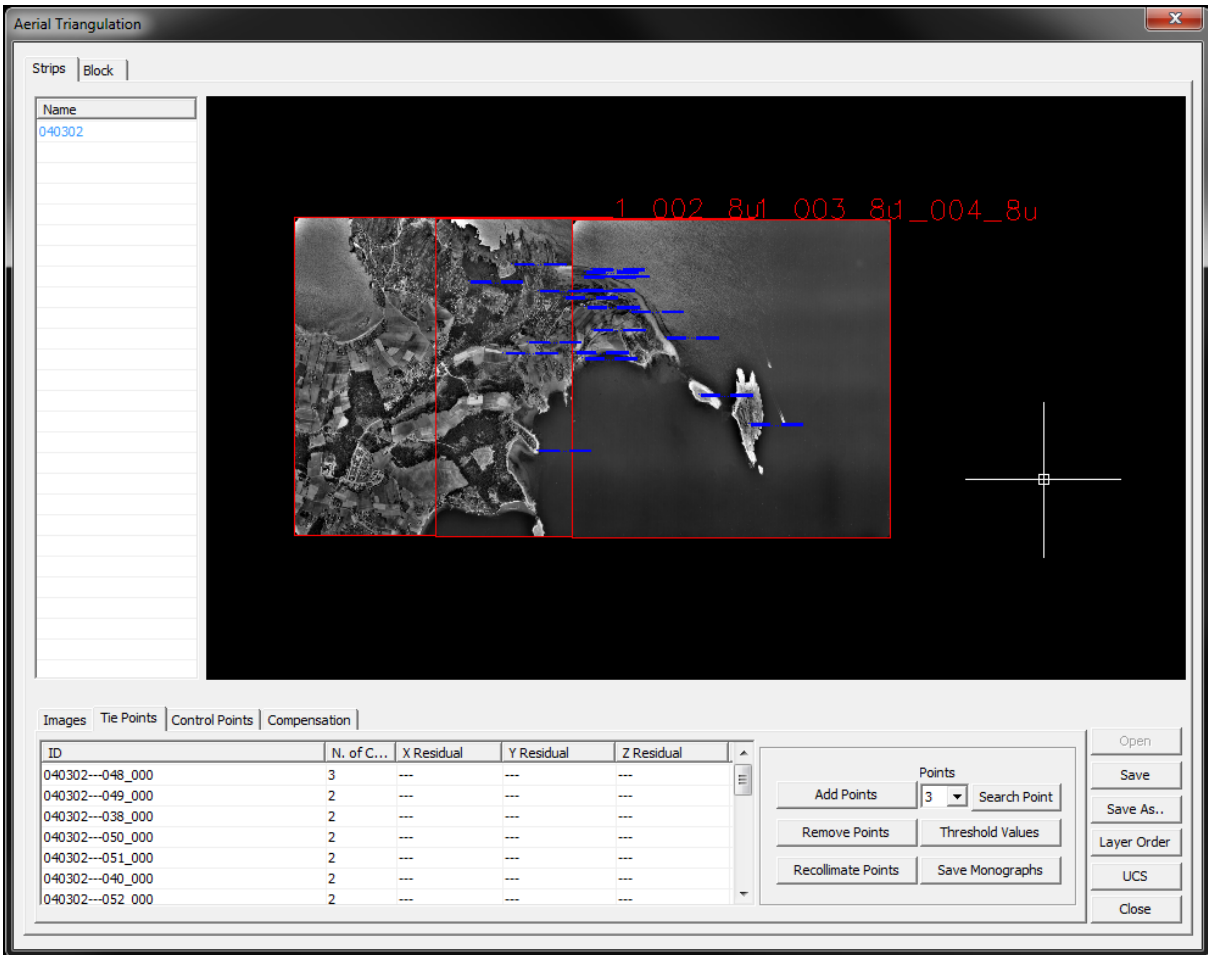
Anyhow a significant number of tie points were placed [fig. 11]



[fig. 9]
Damage due to handwritten pen marks.

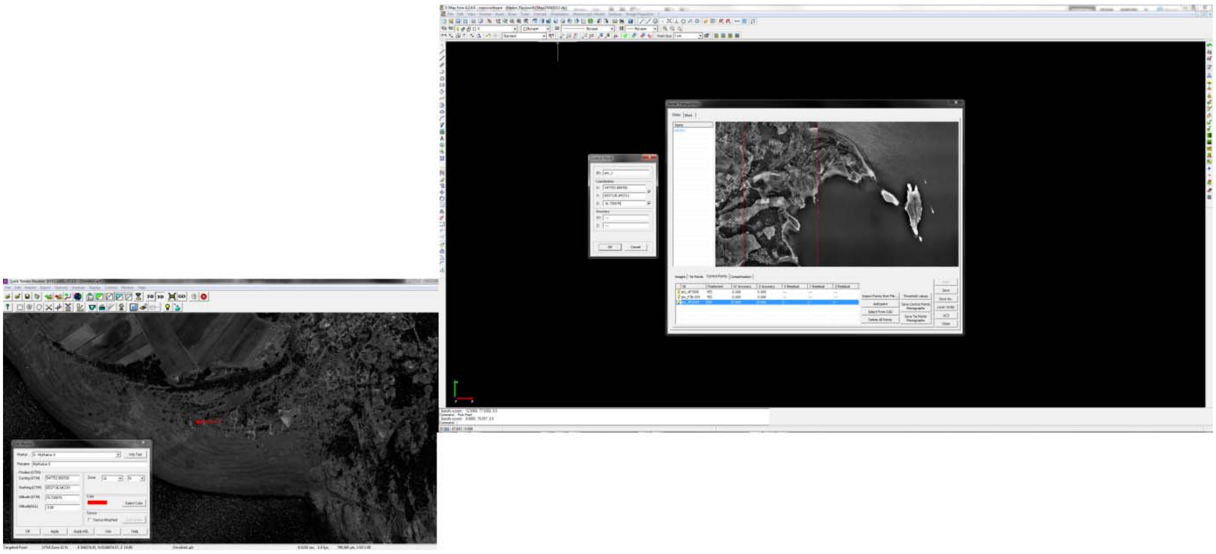


[fig. 10]
Photometric damage. Overexposed film.

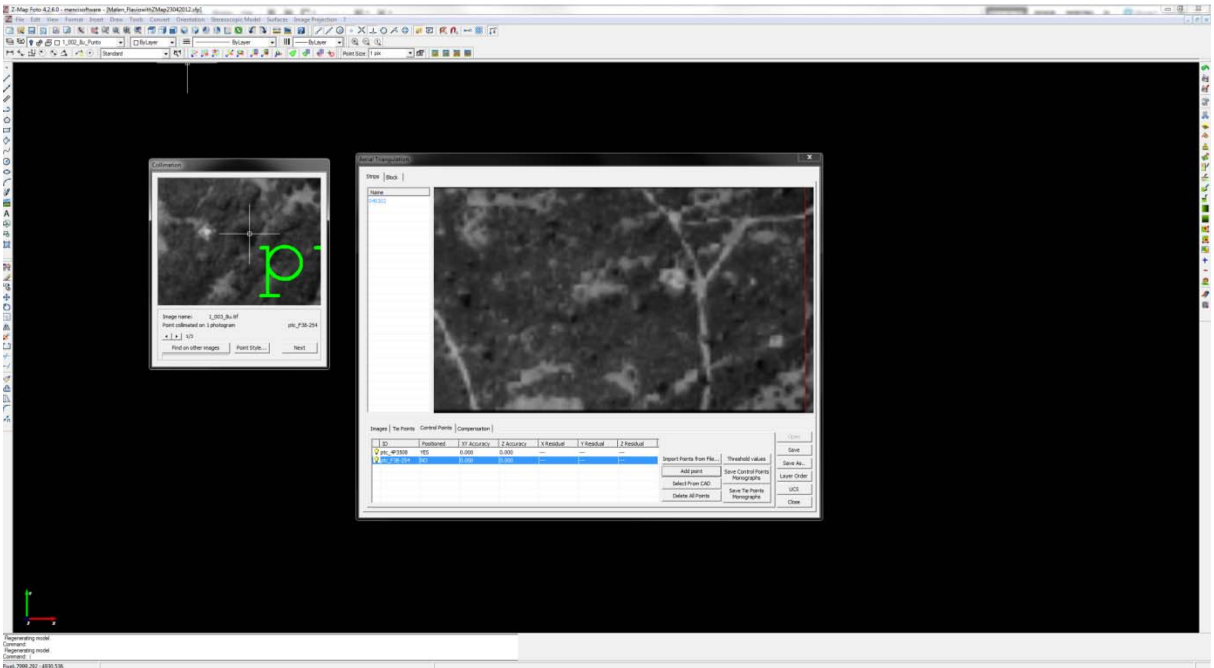


[fig. 11] The tie points

Subsequently, the control points were identified. They represent specific points with assigned 3D coordinates. In this case the coordinates were supplied by the LiDAR model done in 2010 [fig. 12]. This means that the control points are found both physically at Mølen and digitally on the images. It appeared a good choice to assign some of the control points to the ground control points present in the area [fig. 13].

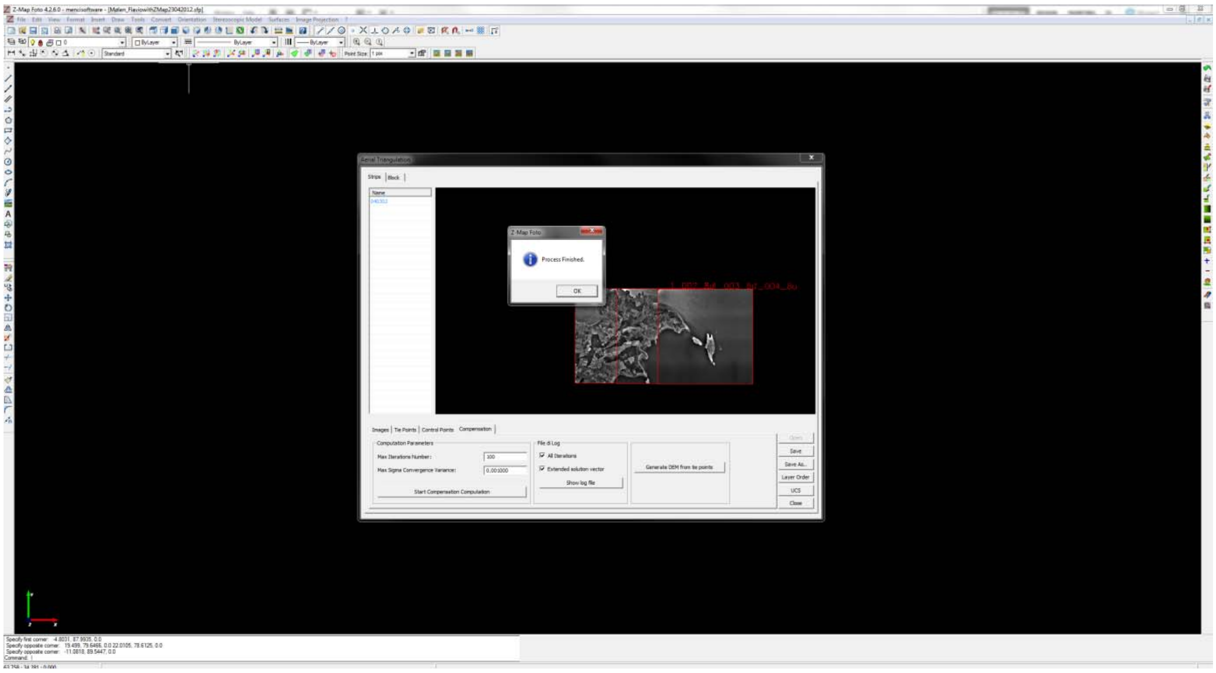


[fig. 12]
The 2010 LiDAR model was used to source the coordinate system of specific points, mutually recognised in the LiDAR and on *Z-Map Foto*.



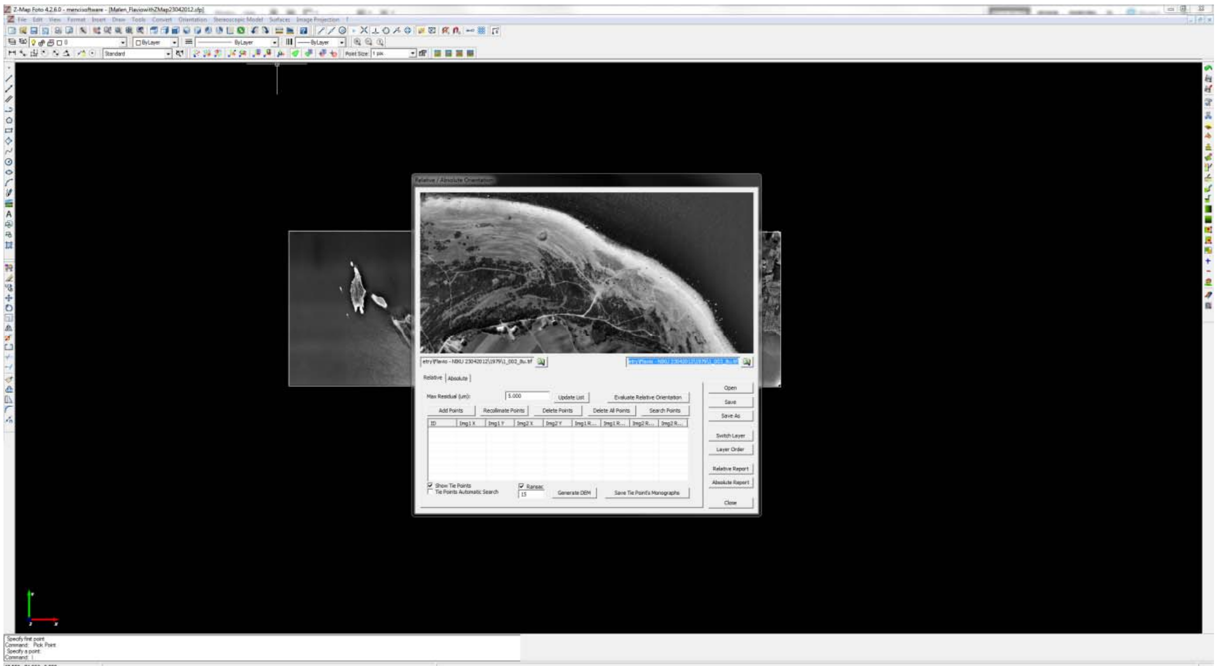
[fig. 13]]
Ground control points mutually identified on the LiDAR and on the historical image.

After this, the compensation was carried out [fig. 14] as a necessary step before being able to generate a DEM. In this process, all the previous passages were taken into the algorithm and processed in order to understand how efficient the points were. This is important since it might result in a better or worse 3D model.



[fig. 14] Compensation.

It was decided also to try the relative/absolute algorithm in order to compare the possible different results. The relative-absolute orientation is used when it is necessary to orient a couple of images in space. It is performed after the internal orientation and built around each image. To obtain an external orientation with this method, it is necessary to define a relative orientation and then to continue with the absolute one. The relative orientation is therefore based on Tie Points [fig. 15].



[fig. 15] Tie points

3 Results

The compensation process demonstrated sound residual for a number of coordinates, but also high residual values both for the tie points and for the control points. This means that the two point clouds - the photogrammetry-generated and the LiDAR-generated DEMs would have to be analysed according to their different accuracies. This is due to a number of factors where the semi-automated technique, compared to an airborne laser scanning, and the physical condition of the pictures from 1979 are some of them.

The test was divided in subsequent goals that we successfully achieved. Starting from a digitalization of the historical material, it was fundamental then to note the technical impediments present on the images. The aim of these first two actions was to identify where it was possible to have material of sufficient quality to proceed with a 3D generation via software. The third step was actually to generate a 3D model in *Z-Map Foto*. We found the resulting model not to be applicable for change detection which means that the last goal was not fulfilled in this test. However we will recommend a continuation of this strategic research, utilizing other and better suited source data.

The results are thus promising, and some positive outcomes have been demonstrated. Nevertheless it was not possible to carry out a comparison, via Quick Terrain Modeler software, of the two diverse 3D models within the frame of this study.

4 Conclusion

Creating a 3D model for cultural heritage monitoring at a landscape scale should be a strategic research activity. Trying to associate data derived from historical aerial photos with LiDAR datasets has hardly been carried out within the research field of cultural heritage, and our study show that there is a great potential that needs to be further developed.

This preliminary study appoints the evaluation concerning what the most critical aspects of these techniques are, and what improvements will be possible in future studies. What is significantly important is to have the means to analyse diverse historical aerial photographic materials. This will allow the evaluation of a protocol of choices to help identify whether a dataset can be used or not. When comparison of landscape changes is the focal point, targeted areas must be studied. Subsequently, it will be fundamental to improve the appropriate software analysis in order to generate comparable 3D models.

In Norway a great number of aerial photos derived from diverse flights conducted during the 1930ies and onwards are kept in archives. Being able to monitor and compare the modifications of the heritage in place seems an extremely useful tool. The information algorithms already exist. Time and research together will surely allow a deeper analysis of the datasets, thus allowing a better understanding and safeguarding of cultural environments and landscapes.

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