

## MEDIUM-FORMAT CAMERAS AND THEIR USE IN TOPOGRAPHIC MAPPING

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### ABSTRACT:

Based on practical experiences with large-format aerial cameras the impact of new medium-format digital cameras on topographic mapping tasks is discussed. Two new medium-format cameras are investigated with respect to elevation accuracy, area coverage and image quality. The produced graphs and tables show the potential of these cameras for general mapping tasks. Special attention is given to the image quality of the selected cameras. Applications for the medium-format cameras are discussed. The necessary tools for selected applications are described. The impact of sensors for georeferencing, multi-spectral images, and new matching algorithms is also dealt with. Practical investigations are carried out for the production of digital elevation models. A comparison with large-format frame cameras is carried out. It is concluded that the medium-format cameras have a potential for mapping of smaller areas and will be used in future in true orthoimage production, corridor mapping, and updating of maps. Their small dimensions and low weight allow installation in small airplanes, helicopters, and high-end UAVs. The two investigated medium-format cameras are low-cost alternatives for standard mapping tasks and special applications. The detection of changes in topographic databases and DTMs can be carried out by means of those medium-format cameras which can image the same area in four bands of the visible and invisible spectrum of light. Medium-format cameras will play an important role in future mapping tasks.

### 1. INTRODUCTION

Mapping of topographic features has changed with the upcoming of digital aerial cameras. It has become fully digital and to a high extent automatic. High demands of the users of topographic databases, orthoimages, and digital terrain models have to be met. The mapping industry is challenged by low prices of these products and short production times. The instrument making industry has improved the tools and considerable progress has been achieved in the last 10 years. The cameras, for example, became small and compact, but the amount of pixels per frame became higher and higher. Figure 1 depicts this progress. Features for the film-based wide angle camera, the digital large-format frame camera of the first generation, and the digital large-format camera of the second generation, and the latest medium-format digital frame camera is presented. Images of the medium-format cameras have a format of 54 mm x 40 mm and between 60 and 80 million pixels (MP) per frame. They have special solutions for generation of colour images and compensation of image motion. In first applications, the medium-format cameras were used in combination with laser scanners where the imagery helped to interpret the laser point clouds. Many other applications are possible and were also carried out. An introduction and overview of medium-format cameras is given by (Grenzdörffer, 2010). The recent announcement of two new medium-format cameras with advanced features and new auxiliary equipment as well as of new processing tools started this investigation. It is the goal of this paper to redefine the potential of medium-format cameras for topographic mapping using up-to-date cameras. The conclusion will be based on practical work with imagery of a test flight and the use of its imagery in standard topographic mapping and some other applications. A comparison between large-format and medium-format cameras is also a goal of this paper.

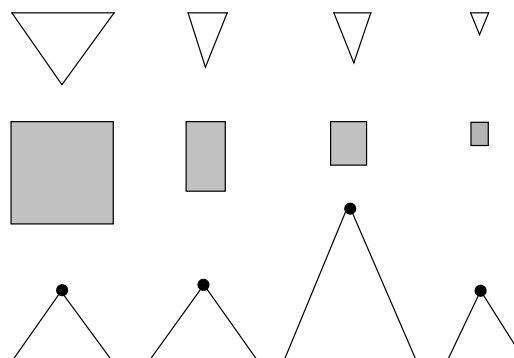


Figure 1. Features of aerial frame cameras. The symbols mean: Columns from left to right: Film-based wide-angle camera, digital large-format frame camera of first generation, digital large-format camera of second generation, and latest medium-format digital frame camera. Rows from top to bottom: Field of view (FOV) in the direction of flight, area of the output image, and flying height for the same ground sampling distance together with FOV across the direction of flight and swath width.

### 2. NEW CAMERAS OF THE MEDIUM FORMAT

The lately announced medium-format cameras are the Leica RCD30 and the Trimble TAC 80. They are described in detail in (Wagner, 2011) and (Trimble, 2011).

The Leica RCD30 camera produces natural color and false-color images by one camera head. Natural color is accomplished by means of a Bayer array. The infra-red (NIR) band is imaged on a second CCD with pixel size of 6  $\mu\text{m}$  x 6  $\mu\text{m}$ . The RGB

bands and the NIR band are co-registered and corrected for geometric and radiometric errors in post-processing. The colour depth is 8 or 16 bit. Two lenses with  $f=50\text{mm}$  and  $f=80\text{mm}$  can be interchanged. Both lenses have a central shutter with automatically controlled aperture. The maximum frame rate is about one frame per second. The RCD30 can be used as a standalone camera system or in combination with laser scanners.

The Trimble TAC 80MP camera can be equipped with several lenses and sensors. The 80MP version has a small pixel size of  $5.2\text{ }\mu\text{m} \times 5.2\text{ }\mu\text{m}$ . Colour or false colour images can be taken but not at the same time. False color photography requires another lens/sensor/filter combination. The colour depth is 16 bit per color. The camera uses a PC for recording of data. The 60MP-version (aka. P65+47mm) has the same format but a larger pixel ( $6\text{ }\mu\text{m} \times 6\text{ }\mu\text{m}$ ). The applied lenses have a relatively high distortion which can be corrected in the photogrammetric processing by using parameters determined in a calibration. The same is true for deviations of the principal point from the middle of the sensor.

Table 1 summarizes the features of the two medium-format cameras. The image size and the base/height ratio for the 50 mm lens is the same for both cameras. The TAC 80MP has a smaller pixel. By means of these design parameters some performance parameters for mapping can be estimated.

features	RCD30	TAC 80MP
<b>sensor:</b> pixel size [ $\mu\text{m}$ ]	6.0	5.2
image size in flight direction [pel]	6708	7760
[mm]	40.2	40.4
across flight direction [pel]	8956	10328
[mm]	53.7	53.7
number of pixels per frame [MP]	60	80
<b>lens:</b> focal length [mm]	50	50
	80	35, 60, 72, 100
<b>base/height ratio</b>	0.32	0.32,
at 60% forward overlap	0.20	0.46, 0.27, 0.22, 0.16

Table 1. Features of two new medium-format aerial cameras

### 3. PERFORMANCE PARAMETERS OF THE TWO NEW MEDIUM-FORMAT CAMERAS

Important performance parameters of a camera system are area coverage, elevation accuracy, and image quality.

#### 3.1 Area coverage

In most of the mapping projects a certain ground sampling distance (GSD) is specified. When  $\text{GSD}=10\text{ cm}$  and lenses with  $f=50\text{ mm}$  are chosen, the area coverage can be calculated (cf. Table 2). The image size across the flight direction on the ground (aka. swath width) determines the number of flight lines in large area projects. It is a factor of economy. The TAC 80MP has a 1.3 times larger area coverage than the RCD30. In comparison with large-format cameras the smaller format of the medium-format camera is its biggest drawback (cf. Figure 2). For example, the new large-format UltraCam-Eagle of Microsoft/Vexcel, described in (Gruber et al., 2011), has a 1.94

times bigger swath width than the TAC 80MP when the same GSD has to be achieved.

features	RCD30 $f=50\text{ mm}$	TAC 80MP $f=50\text{ mm}$
flying height [m]	833	962
image size across flight direction [m]	896	1033
image size in flight direction [m]	671	776
area coverage (foot print) [ $\text{km}^2$ ]	0.6	0.8

Table 2. Flying height, image size and foot print at  $\text{GSD}=10\text{cm}$

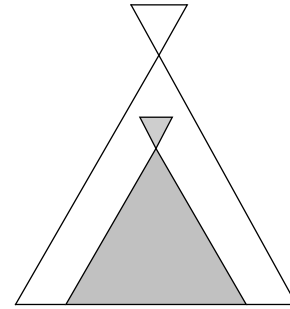


Figure 2. Comparison between large-format and medium-format cameras. At the same FOV and image scale (GSD) the medium-format camera has a much smaller swath width.

#### 3.2 Elevation accuracy

The potential with regard to the elevation accuracy is of great importance for production of digital surface and terrain models. By means of the design parameters of the cameras the elevation accuracy can be estimated by equations 1 and 2.

$$\sigma_h = \frac{f}{b'} \cdot \frac{\sigma_{px'}}{pel} \cdot GSD \quad (1)$$

$$\frac{\sigma_h}{h} = \frac{\sigma_{px'}}{b'} \quad (2)$$

where  $\sigma_h$ = elevation accuracy  
 $h$  = (mean) flying height above ground  
 $f$ =calibrated focal length  
 $b'$ =image base  
 $pel$ =side of the pixel  
 $\sigma_{px'}$ =parallax accuracy related to the image

The parallax accuracy ( $\sigma_{px'}$ ) can be derived from practical tests. The DEM generation by means of different digital large-format cameras revealed an average value of  $\sigma_{px'}=0.5\text{ pixel}$  (Höhle, 2011). It is assumed that the value can also be applied for the new medium-format cameras. In this way, all digital aerial cameras can be compared on the basis of their design parameters (base/height ratio, pixel size).

In order to compare with large-format frame cameras the Hexagon/Intergraph DMC and DMCII-250 are used as examples. They represent the first and the second generation of digital large-format frame cameras. The DMC has a pixel size of  $12\text{ }\mu\text{m} \times 12\text{ }\mu\text{m}$  and  $b/h=0.31$  at 60 % overlap, the corresponding values for the new DMCII-250 are  $5.6\text{ }\mu\text{m} \times 5.6\text{ }\mu\text{m}$  and  $b/h=0.29$ . More details on these cameras are published in (Hinz et al., 2000) and (Neumann, 2011). Table 3 displays the relative

and absolute elevation accuracy based on the design parameters of the camera and the assumed parallax accuracy of 0.5 pixels.

camera	relative accuracy ( $\sigma_h/h$ ) [% of flying height]	absolute accuracy ( $\sigma_h$ ) [GSD]
TAC 80MP (f=50mm)	0.16	1.55
RCD30 (f=50mm)	0.19	1.55
DMC	0.16	1.63
DMCII-250	0.09	1.71

Table 3. Elevation accuracy of digital aerial frame cameras at 60% forward overlap and parallax accuracy of  $\sigma_{px}=0.5$  pixels

From Table 3 it can be read that both medium-format cameras may automatically derive elevations with an accuracy of  $\sigma_h=1.55 \cdot \text{GSD}$  corresponding to 15.5 cm at  $\text{GSD}=10$  cm. This is a better absolute elevation accuracy than with the large-format cameras. If the elevation accuracy is related to the flying height then the relative accuracy of the new DMCII-250 camera exceeds both medium-format cameras. This theoretical consideration on the basis of the design parameters of the cameras has to be proven in practical tests of DEM generation. The quality of the images will have influence on the parallax accuracy.

### 3.3 Image quality

Good image quality requires first of all a good lens. Several parameters have to be considered. The resolving power (R) of the lens, measured in line pairs per millimetre (lp/mm), has to be as high as

$$R=1000/(2 \cdot \text{pel}) \quad (3)$$

where pel=distance between two pixels, in  $[\mu\text{m}]$ .

This value is also known as Nyquist frequency. The camera should therefore be equipped with a lens that has such a resolving power (DIN, 2007). In the case of the investigated cameras the required resolution is 83 lp/mm (RCD30) and 96 lp/mm (TAC 80MP), respectively. The lenses of digital cameras are checked by the producers in the laboratory by determining the Modulation Transfer Function (MTF). For different radii the modulation (contrast) of different input frequency (lp/mm) is determined in percent (cf. Figure 3). A typical requirement for lenses used in aerial photography is a contrast in excess of 40% at half of the Nyquist frequency and contrast values below 40% at frequencies twice the Nyquist frequency (Doering et al., 2009). Changes in temperature and pressure may change the performance of the lens if no precautions are carried out by the manufacturer. Other influences on the image quality are the condition of the atmosphere and the proper exposure. Both medium-format cameras can be equipped with different lenses in order to meet the requirements of different applications. The interchanging of the lenses should maintain the interior orientation. Lenses of the two cameras are for example the Leica NAG-D 50 and the Rodenstock HR Digaron-W 50, respectively. Both lenses have a focal length of  $f=50\text{mm}$ , a maximum aperture of  $f/4$  and  $1/1000$  of a second as shortest exposure time. The Leica lens is thermal stabilized. In addition, lens distortion, displacement of the principal point, and light fall-off of the lens are compensated in post processing. Both cameras use Bayer arrays for generation of color images and compensate mechanically for

image motion. The Leica RCD 30 is able to correct in two directions. This may be of advantage at strong lateral wind resulting in deviation of the airplane axis from the flying direction.

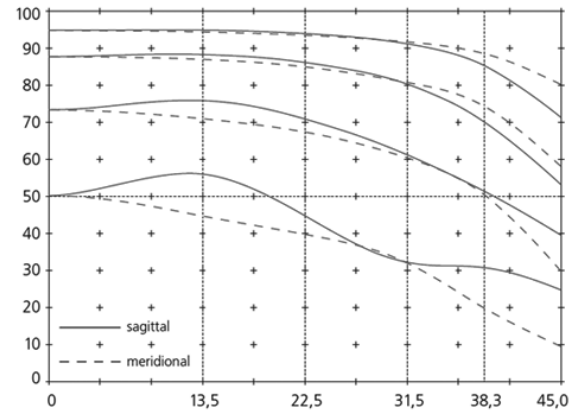


Figure 3. MTF of Rodenstock HR Digaron-W 50mm f/4 lens for aperture 5.6. The curves represent the 80, 40, 20 and 10 lp/mm frequencies. Source: (Rodenstock, 2011)

### 3.4 Other features of the two medium-format cameras

Both cameras are compact and of low weight. Such features enable the use in small airplanes, helicopters and high-end Unmanned Aerial Vehicles (UAVs). Installation in an external pod avoids expensive modifications of the vehicle. An overview on UAVs is given by (Everaerts, 2009). Furthermore, these cameras are prepared to meet the environmental conditions in higher altitudes. Other features are high frame rates, a gyro-stabilized mount, and position and attitude measuring devices (GNSS/IMU). The combination with a laser scanner opens up for other applications and performances. In comparison with the large-format cameras the price is much lower. The operational costs, however, become higher when large areas have to be mapped. The number of strips to be flown and thereby the length of flight will increase. In the example of Figure 2 the flight with the medium-format camera (TAC-80) is 1.94 times longer than with the large-format camera (UltraCam-Eagle). The costs of flying will increase about by the same factor.

## 4. SOME MAPPING TASKS

Topographic mapping comprises the production of line maps, orthoimages, and digital elevation models. These standard tasks, which national mapping organizations and private companies have to accomplish, may also be carried out by medium-format cameras. But the areas to be mapped by means of these cameras should not be very large. The production of line maps and topographic data bases requires extensive manual work and is often outsourced. Updating of maps and topographic data bases may become tasks for medium-format cameras. Mapping of narrow corridors is certainly an application for the medium-format cameras. The production of orthoimages of small areas (e.g. street crossings, railway stations, gravel pits) requires high image quality, small GSDs and digital terrain models. Mosaicking of several orthoimages is necessary and requires good colour balancing. If orthomosaics are combined with line maps the production of true orthoimages may become necessary. They are produced from very dense digital surface models (DSMs) and highly overlapping imagery. The automatic generation of elevations by means of images requires imagery of high geomet-

ric and radiometric resolution. The generation of digital terrain models (DTMs) needs also efficient filtering of the matched points. All processing should be carried out with a high degree of automation and reliability. Medium-format cameras may also find application in remote sensing tasks like classification of land cover. There will also be new mapping tasks, e.g. the generation of digital surface models, 3D city models, true orthoimages, false-colour orthoimages, slope and erosivity maps, and flood risk maps. Also the updating of 2D topographic data bases and DTMs can take advantage of medium-format cameras because the areas to be mapped are often small. The involved processes (matching, filtering and change detection) require features which the new generation of medium-format cameras and new software tools can fulfil. Figure 4 depicts a generalized flow chart how such products could be produced.

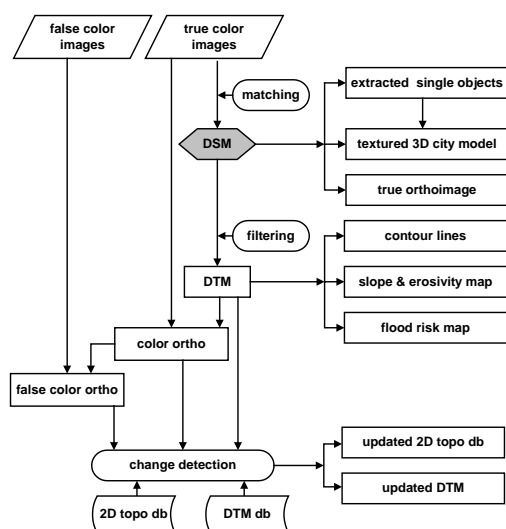


Figure 4. New mapping products and their generation

## 5. PRACTICAL INVESTIGATIONS

Practical investigations are carried out with image material of the new Leica RCD30 camera. The image data are first described and then used in a few of the above described new applications. The new tools applied in the different applications are mentioned.

### 5.1 Used imagery and its quality

Multispectral images consisting of four bands (RGBN) were taken with the Leica RCD30 camera equipped with the NAG-D 3.5/50 lens in June 2011. Several strips with GSD=5 cm were flown with about 75% end lap and 30% side lap. The photographed area contained buildings and vegetation near a small town in Switzerland. The images have small tilts ( $< 0.2^\circ$ ) thanks to the used gyro-stabilized mount. The drift angle is relatively high (about  $17^\circ$ ) which will challenge the forward motion compensation (FMC) of the camera. The calibration report informs that the calibrated focal length is  $f=53.00$  mm and that distortion and other geometric errors have been removed. The provided images are also corrected for Dark Signal Non-Uniformity (DSNU) and Photo Response Non Uniformity (PRNU). The orientation data of the images were derived in an aerotriangulation using a few ground control points (GCPs). Image quality may be checked also by the user. For example, the width of stripes on roads may be measured to determine the so-called blooming of the sensor. When big differences between

the widths of bright stripes and dark spaces (a-b) are found, the anti-blooming devices of the sensor may not work properly. Such effect will displace the position of objects with high contrast. Furthermore, the PRNU may be tested at objects in different image positions. Light fall-off of the lens and non-uniform pixel sensitivity may be discovered then. The PRNU influences the results of classifications.

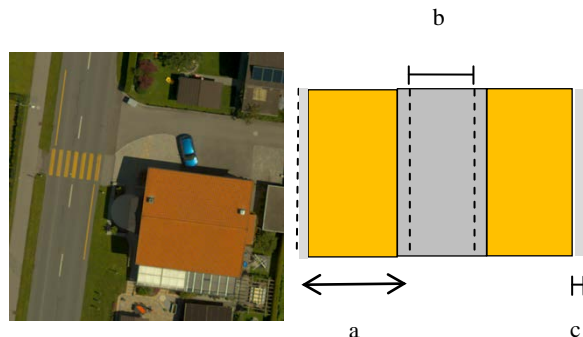


Figure 5. Stripes on roads at different image parts may be used to check for blooming and PRNU

Tests with the RCD30 camera showed satisfying results (cf. Table 4). The measured intensity values are equal in the middle and the edge of the image; the differences between the stripes and spaces were 2.6 and 2.2 pixels respectively. The displacement (c) is only a quarter of these values. At images with GSD=5 cm the edge of a stripe is then shifted by about 3 cm. The end of bright stripes on dark roads should therefore not be used as GCP. The condition of this PRNU test, that the actual widths have to be equal in size, was not verified in the field.

image position	intensity [DN]		width [pel]		difference [pel]
	a	b	a	b	
centre	138	95	11.7	9.1	2.6
edge	135	96	11.8	9.6	2.2

Table 4. Checking of RCD30 images for PRNU and blooming

### 5.2 Applications

The applications dealt with are DSM generation, building generation, production of true and false-colour orthoimages, and updating of 2D topographic databases and DTMs.

**5.2.1 DSM generation:** The digital surface models are of interest to the mapping industry because they are the prerequisite for the automated extraction of buildings, bridges, etc. Several new tools were created, e.g. the release 5.4 of Trimble/Inpho's Match-T program. The new features of this program are generation of a very dense point cloud, short processing times, support of large data sets, and distributed processing (Heuchel et al., 2011). In general, the matching of images with poor texture may lead to blunders and inaccuracies of the derived elevations. High image quality and high dynamic range can avoid or reduce these deficiencies. Figure 6 shows a point cloud derived from RCD30 images and using the new software tool Match-T 5.4. The distance between DSM posts is 0.25 m only. Independent and many check points are necessary in order to determine the absolute elevation accuracy of the test. The elevation accuracy has been checked by means of a few GCPs and resulted in  $\sigma_h=0.04$  m and  $RMSE_h=0.22$  m. A very dense and positional correct DSM can also be the base for line mapping of modest

planimetric accuracy. Such an automated approach may replace the current manual mapping technology. However, some manual editing work will still be necessary.

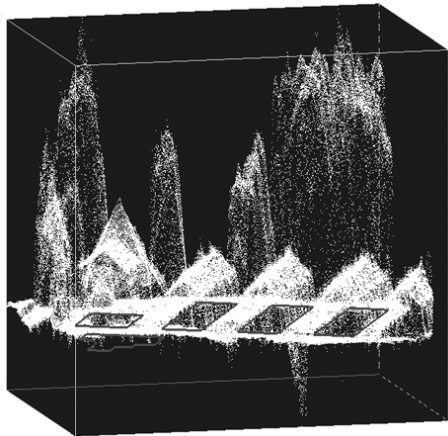


Figure 6. Profile data of DSM result

**5.2.2 Building generation:** The production of 3D building models is a rather new task for the mapping industry. They are produced with different levels of detail (LOD). Simplest is the wire frame model (LOD1); more complex are building models with generalized roof shapes (LOD2) or with additional textured facades (LOD3).

Advanced tools for the generation of buildings are at disposal, e.g. the “BuildingGenerator” of Trimble/Inpho, which starts from a georeferenced point cloud for modelling the roofs. In addition, a DTM and 2D data of buildings (footprints) are required, in order to generate building models of the LOD2 type. Ridge lines are generated by intersecting segmented tilted planes. Lifting the footprint up to the modelled roof then creates the building model. The modelling of buildings can to a large extent be carried out automatically. The footprint may be generalized and various roof types (flat, saddle back, hip, mansard, crippled hip, and tent roof) can be created. Several parameters have to be specified including the required quality in modelling. More details are described in the manual of the “BuildingGenerator” (Trimble/Inpho, 2009). The use of a 3D-editor in combination with a database is of advantage. Figure 7 depicts a wire frame model of houses which were derived semi-automatically.

**5.2.3 Production of true orthoimages:** Orthoimages are usually produced by means of a digital terrain model. In standard orthoimages the objects above the terrain are displaced and details near the elevated objects are hidden. True orthoimages avoid these problems and should therefore be produced for urban areas. A prerequisite for the production of true ortho-images are images of large forward and lateral overlap. The orthoimage can then be generated from several images and details near buildings are contained in the orthoimage. Building facades will be invisible in the true orthoimage (cf. Figure 8).

**5.2.4 Production of false-colour orthoimages:** The generation of false-colour orthoimages is easily to accomplish from images of a multi-spectral camera using co-registration of the NIR band with the RGB bands. The same orientation and DTM can be applied. The generation of the DTM from the point clouds requires filtering so that only elevations representing the bare earth will remain. It also includes the removal of blunders. This process is to a large extent carried out automatically. The gaps

have to be filled again with points by means of interpolation using surrounding points. The produced DTM is a base for other applications such as derivation of contour lines, slope and erosivity maps, and maps for flood risks (cf. Figure 4).

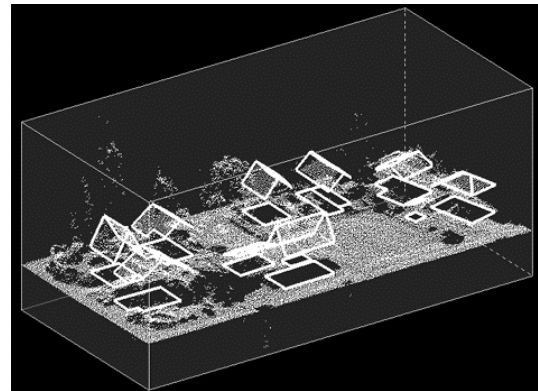


Figure 7. Building model. The building roofs were extracted from a very dense point cloud generated from RCD30 imagery.

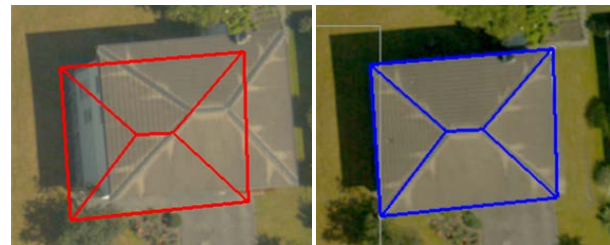


Figure 8. Building and vector plot in orthoimage (left) and true orthoimage (right).

A false-colour orthoimage is a prerequisite for other products based on remote sensing techniques, e.g. applying the normalized difference vegetation index (NDVI) allows separating between vegetation and non-vegetation (cf. Figure 9). More advanced software use elevation and vegetation data in order to separate trees, vegetated ground and non-vegetated ground.

**5.2.5 Updating of 2D topographic databases and DTMs:** An important task for mapping organizations is the updating of topographic databases. The detection of changes in the landscape is a key process. The combined use of elevation and vegetation maps will assist to detect new or missing buildings. The use of false-colour orthoimages and DSMs for updating of topographic 2D databases has been demonstrated in (Champion, 2009). The use of a digital aerial camera which records four bands simultaneously is a very useful tool for such a task.

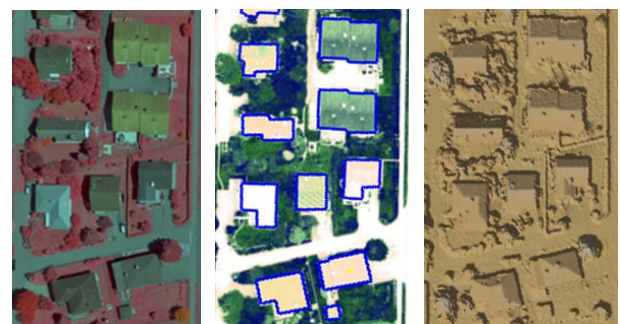


Figure 9. False colour orthoimage, NDVI map and shaded DSM



The updating of DTMs can be carried out by means of overlapping orthoimages. If the elevation model used in the generation of the orthoimages had errors they would show up as parallaxes between the two orthoimages. The parallaxes can automatically be measured and converted into elevation differences. Details on this automated approach of DTM correction has been published in (Höhle and Potuckova, 2006).

## 6. DISCUSSION

The ground coverage of the output image of the two considered medium-format cameras is about four times smaller than the coverage of a large-format digital frame camera at the same ground sampling distance. The smaller format results also in lower relative elevation accuracy. This drawback may be compensated due to higher geometric accuracy of the one-chip solution, which still has to be proven in test field calibrations. Other fundamental differences between medium- and large-format digital frame cameras are in the generation of colour and in image motion compensation. The used lenses should be adapted to the resolution of the sensor. Advantageous for medium-format cameras is low weight, compactness, and price. Also the flexibility due to exchangeable lenses and smaller amount of data per image are advantages at special applications. The use of medium-format cameras is especially suitable for small-area projects which exist in corridor mapping, generation of city models, and updating of topographic databases. The presented applications may use a medium-format camera; and together with advanced processing tools new products like DSMs, true orthoimages, and 3D building models can be generated nearly automatically. More practical work with medium-format cameras is necessary in order to prove these findings.

## 7. CONCLUSIONS

Advanced medium-format cameras may produce imagery of good quality. Tests with the RCD30 camera revealed uniform photo response and small blooming at edges of high contrast. Mapping tasks such as orthoimage production and stereo compilation can be carried out accurately and reliably. Digital surface models can be produced with a high density and good vertical accuracy. The automatically generated DSM is the prerequisite for several new applications. Medium-format cameras with co-registration of a near-infrared image and radiometric calibration of all sensors will find new applications in remote sensing tasks. Medium-format cameras are smaller and more compact and can therefore be installed in small airplanes, helicopters, and high-end UAVs. They have a lower price and very likely also smaller operational costs than the large-format cameras. The user of medium-format cameras will therefore have a better competitive position in getting mapping contracts. The medium-format cameras will especially be used in small area projects such as mapping of narrow corridors, generation of city models, and updating of topographic databases and DTMs.

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