MONITORING URBAN DEVELOPMENT OF SMALL CHINESE CITIES USING INNOVATIVE AERIAL SURVEYING TECHNOLOGIES

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ABSTRACT:

Beside the enormous grow of Chinas mega-cities, also small cities and big villages show up an urban sprawl that makes a monitoring essential. Especially in the eastern part of the country, forced by the economic growth, the sprawl of urban fabric is extreme. This causes a need for a frequently and rapid monitoring in order to take pace in mapping and documentation. The typical turn rate of countrywide aerial surveys is not convenient to solve this task. Small scale, long intervals, and bad quality of the data hamper doing the job with sound scientific methods. The Hebei Bureau of Surveying and Mapping finally found a smart solution in the year 2006 and meanwhile ran several campaigns of even big areas. A combination of a medium format camera, a gyrostabilizer and a professional FMS were installed on a Trike for aerial survey missions. Quality and operability will be shown in the following paper.

1. TASK AND NEEDS

Chinas cities show up an enormous urban sprawl especially in the eastern part of the country where economical growth is strongest. This urban sprawl is not anymore focused on cities only; even small villages show up growing urban fabric. Beside that, infrastructure must take pace with the urbanisation. To monitor this urban growth, to create actual maps and to produce data for planning activities is one of the main tasks of the Bureau for Mapping and Surveying.

The Department for Surveying and Mapping of the Province Hebei has to work on various scales and is faced with the task to deliver actual maps and geo-data in short time intervals. This can not be done with classical surveying since the province Hebei covers the complete surrounding of Beijing. With a coverage of 187,700 km² and a population of 69 Mio., Hebei is a relatively small province but with a very dense population of 363 people /km². This is the reason for the urban sprawl on high level.

To produce the needed data, aerial survey with photogrammetric processing is the most convenient method that delivers a reasonable accuracy in a short time. Especially to monitor urban dynamics, it is important to get the source data on an exact timestamp. While field survey needs several month to map even small cities, the aerial images are taken in few hours.

Start own aerial surveying is faced with several limits. Access to suitable aircraft is limited as well as the availability of aerial cameras is not easy. There are difficult regulations concerning flight altitude, as lower as easier permission is achievable. Normal mission altitudes are controlled by governmental and military organisations, which mean that it takes long to run the mission. Indeed, there are other limits, especially the budget. That is why alternatives have been tested to produce data suitable for cadastral and topographical mapping. Actually, a Microlight-Trike with a stabilized mount carrying a medium format digital camera was found as a good and flexible solution. This innovative system has proven its operability.

2. TECHNICAL SOLUTION

Basis of this innovative mapping system is a medium format digital Camera, a Rollei AIC P45, that is mounted on an AeroStab-2, which is a three axis gyro-stabilised mount. This equipment is used in a Microlight-Trike, which are easy to transport since they can be packed to a small volume.

Figure 1: Microlighte-Trike as a platform for aerial surveying using Rollei AIC, AeroStab-2 and AeroTopoL FMS

2.1 Microlight Delta Trike

The Microlight Delta Trikes are produced in Australia and frequently in China. The advantage of such an aircraft is the price on one side and the possibility to transport it easily on the other. It can be shipped in a lorry or a trailer and build up within 1 hour. These Trikes need only 50m of flat terrain, either asphalt or grass, for starting and landing. With its 70 litres tank, the range exceeds to more than 600 miles. Due to the strong Rotax motor, the payload is 200 kg, fine for Pilot, Operator and the equipment.

Pilot and operator can do the job in the hanging open cabin below the wings. Since these trikes behave sensitive in the air, a fast and precise stabilisation must be used to receive data

for a proper photogrammetric handling. The behaviour is different to other aircrafts, strong drift has to be expected. The real big advantage is the low minimum speed of such Trikes (about 60 km/h) which enables collecting data with high resolution on low altitude without forward motion blurring. For storing the photogrammetric equipment, two boxes have been designed which carry camera and stabilizer as well as the PC and powering units. The FMS (Flight Management System) is installed on a Field PC (Panasonic CF-18) managed by the operator sitting the back while a second pilot is mounted on the cockpit to navigate the pilot.

Figure 2: Pilot and Operator are ready for take-off, in background the lorry for transporting the trike

2.2 Camera and Stabilizer

The Rollei AIC modular uses a 39 MPIX digital back from Phase one, one of the best sensors available for medium format cameras. The Camera itself uses a central shutter lens, highly recommended for aerial survey. With a speed of 1:1000 and an aperture of 1:2.8, the 50 mm lens is a good compromise for stereoscopic mapping and orthophoto production. The engineers of Rollei have reduced most mechanical parts that make the camera really robust and reliable.

Figure 3: Rollei digital aerial camera with the AeroStab-2

The AeroStab-2 is a full compensating camera mount that is designed for small and medium sized cameras. The AeroStab-2 compensated in Roll and Pitch 23° with a speed of 10°/s. Heading-compensation is +- 20° with 5°/s. AeroStab-2 uses a MEMS based AHRS in combination with a vector GPS board. Like that, it also gives a fast navigation

solution to the FMS and controls the camera. AeroStab-2 triggers the camera by commands from the FMS and takes the event for producing projection centres in 1 m accuracy and the related rotations with better 1 degree. This is accuracy is fine for an initialisation in automated aerotriangulation programs. During release, the stabiliser gets "frozen" until the event mark has expired more than 50 msec. This prevents against blurring. In combination with the FMS, a full heading compensation was realised to correct the drift to the planned direction instead to the ground track only. The IMU data are handles with 100 Hz while GPS and True heading are handles with 10 Hz. As a navigation solution, 10Hz data are transferred to the AeroTopoL FMS.

2.3 AeroTopoL FMS

AeroTopoL is a relatively new FMS that comee in a bundle with the AeroStab-2. AeroTopoL is a innovative GIS based FMS that perfectly deals with the Rollei Camera and the AeroStab. The Mission planning is extremely powerful and the navigation very comfortable and smooth.

2.3.1 Mission planning:

Due to the GIS-environment of AeroTopoL, reading and writing various raster and vector formats is very easy. The possibility to transform raster data as well as to combine data of various sources and geodetic datum is a very big advantage over traditional FMS. The superimposition of Raster and vector data gives all background information that is needed for a proper planning. As more information is available as better the planning can be done. Useful is the displaying of the planed footprints in combination with a creation of an overlap layer that uses topological analysis to detect areas of certain overlap. This assists nicely to place GCPs.
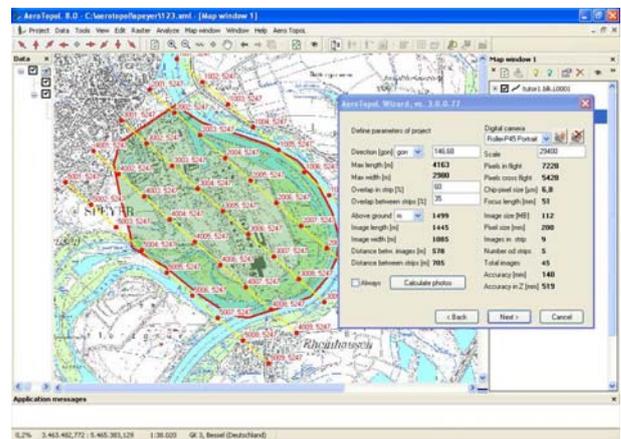
Figure 4: Mission Planning with AeroTopoL FMS

A useful feature is the selection of areas in a seperate layer that can be used as a filter to deactivate images. This possibility enables to plan over a couple of small compartments even the overall area is much bigger. It is also possible to do this for selected parts only e.g. by query the database. In traditional systems, you have to add lines and images and finally to do a lot of manual work. A new feature is the adjustment of the missions over terrain. The DTM can be created out of various data and possibilities to transform existing data into a local coordinate system are practical. The

adjustment over terrain computes enhanced footprints while sticking on an image scale hysteresis and leaving the overlaps on its minimum level. This delivers a rather surprising block of footprints that again can be used for GCP definition.

2.3.2 Mission navigation

A FMS also needs to execute the mission in a sufficient way. Data from AeroStab-2 are sent with 10 Hz for position and attitude of the aircraft and are updated even in-between if an exposure pulse was registered. AeroTopoL itself sends commands to release the camera and to control the AeroStab-2 via one serial interface only. Data from GPS are handled in AeroTopoL extremely fast and displayed in the map-window and/or by the software-based instruments immediately. The moving map functionality using vector and raster benefits together with the on-time computation of the real measured footprints. This gives immediate information about the proper coverage of the area. If some parts seem to be badly overlapped or covered, manual imaging can prevent in doing additional flights.
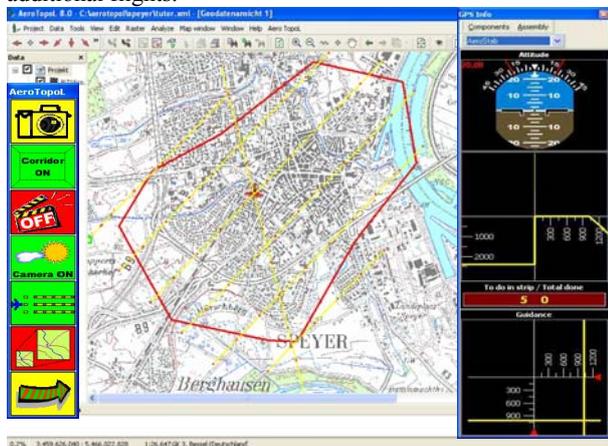
Figure 5: Main Screen during aerial surveying with AeroTopoL

For a proper navigation, moving map is not practical for pilots. Using standard windows dual screen settings, the pilot can have access either to full application screens or to navigation panels only. These navigation panels show similar to IFR techniques the track data by a cross track indicator and a course finder as well as an artificial horizon. Due to the 10 Hz data input, these instruments react like analogue ones and enable the pilot to keep the track precisely.

Since all data of the received camera pulses are stored in a database, a project can be flown also in two or more days. Access to the DB makes this function possible. End of the mission, all projection centres with their rotations already saved in photogrammetric values assist in speeding up the following workflow. The created vector data can be delivered directly to the customer as a first report since all relevant information (Date, time, Image number…) are stored in the point database. The event-based positioning gives projection centres of 1-2 m accuracy and the roll pitch and heading information is about 1° accurate. The rotations are already recalculated into Omega, Phi and Kappa by using the camera installation information that makes an immediate use in photogrammetric processing possible.

3. MISSIONS

It was not really clear from beginning if a trike is the right aircraft. Test with remotely controlled airships and ultra-light aircrafts were performed in 2005. The result was not convenient. The package consisting of Camera, Stabilizer and Flight Management System was also not purchased before deeper tests took place. Alternatives where observed as well.

3.1 Test project

In April 2006, guest from Germany and the BMS-Hebei met in Beijing to prepare firsts test with a Microlight Trike, the AeroStab-2, Rollei AIC P45 and AeroTopoL. Beside the Trike, all components were just been upgraded to their actual stage. In this test, the camera was mounted in a box below the motor. The complete setup was on an experimental stage, however, main gaol was to test the quality of the images, their coverage and overlaps as well as their final accuracy. Beside that, the workflow was intended to test. As a test site, the village Xiongxian was chosen as a typical example of rapid expanding small cities.
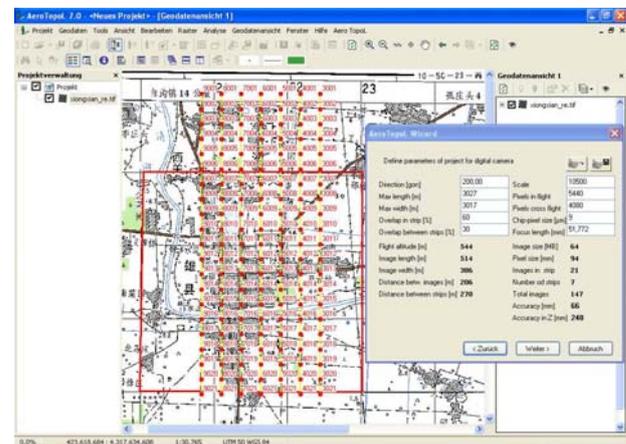
Figure 6: Xiongxian Testsite with the planned mission and the resolution, scale and expected accuracy

It was planed to observe the village with a GSD (Ground Sampling Distance) of 7 cm and overlaps of 60/30%. The expected accuracy in spacing was at 5 cm and in height around 19 cm. A small block of the complete dataset was aero-triangulated using Ground Control Points. The results met the expectation, they were even slightly better in heights. Validating was also done by computing orthophotos and counterchecks the Ground Controls on these data. Stereo-editing and re-measurement of these points also gave a good correlation within the expected accuracy. All photogrammetric processing was done for this test with PhoTopoL and AeroSys.

However, some small problems in the FMS and also the hardware was detected. Especially the Antennas for measuring the True Heading were not sensitive enough and were partly covered by the wings. New antennas were developed for this task, which have a better Signal/Noise ratio especially on the L1 frequency. This one is used for the heading determination. Camera, Stabilizer and FMS was purchased after the test

3.2 Project to test needs of the AeroStab 2

To test if a stabilizer is really needed and to take evidence by scientific methods, missions were done with the stabilizer switched on and with the stabilizer fixed in its neutral position. From beginning were still some slight problems with the heading determination of the GPS Vector board that finally uses the L1 residuals for a precise detection of the antenna orientation. The main problems appeared by the wings and its aluminium frame. This sometimes disturbed the signal and caused a break in the measurement. This problem was overcome using antennas mounted on a big ground-plane on one side and some modification to support the GPS by a gyro aiding on the other. This gyro aiding bridges the signal if lost and assist in a fast reacquisition.

Figure 7: Trike ready for take of with the enhanced antennas for a stabile heading determination
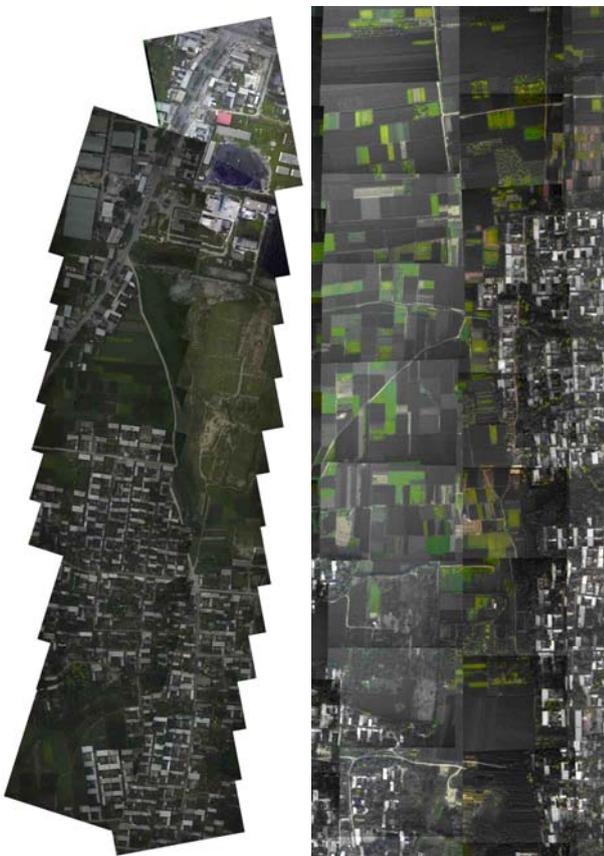
Figure 8: The left image block shows data captured without stabilization, on the right with stabilization

The wind during this mission came from side with 3-5m/s, typical conditions in this area. It is clearly visible that the drift-compensation is essential as well as the compensation of roll and pitch is responsible to keep the side overlaps in a correct limit. Working with uncompensated data will cause much more work beside the risk of holes in the image block.

3.3 "hot" projects

A huge number of mapping projects have been done in 2007 and the expected accuracies always met the expectations perfectly. Since these Trikes can even fly on low altitude, and very slow as well, a wide range of image scales (or better Ground-Sampling-Distances) can be managed without getting blurred images. There is a need to adjust the flight altitude due to legal restrictions many times. That makes such a flexible system usable in most cases. Due to the medium sized format camera, huge amounts of photos per mission are needed and the workflow has to be partly automated to keep pace with the big format cameras. A big advantage is the digital format that delivers better quality than the scanned analogue images. Even in shadows and partly foggy atmosphere, the images can be used without limitations. Perfectly are the data of the AeroTopoL FMS that already gives the projection centre of 1 m and the rotations of 1 degree accuracy. Since they are already in the local coordinate system and recalculated to photogrammetric values Omega Phi Kappa), they can directly be used to set up the software for automated Tie-point measurement. Very useful is the information about the camera mounting which has direct influence on the kappa angle.

Figure 9: Footprints of a 6km² missions over a village flown 610 m above ground (82mm GSD)
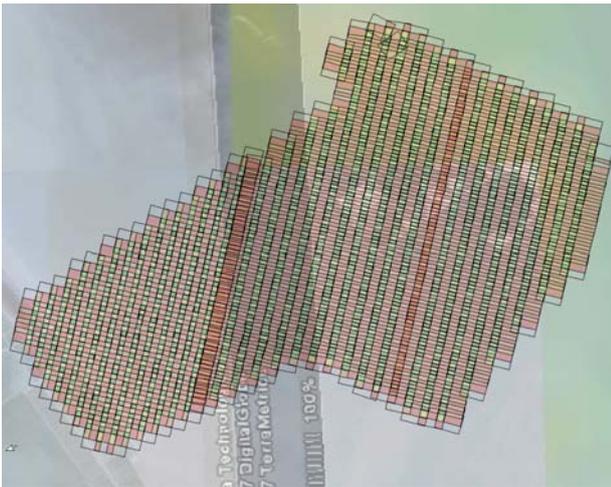
Figure 9: Footprints of a 220km² missions over an industrial area flown 900 m above ground (120 mm GSD)

Inserting a number of GCPs (ground-control-points), the Aero-Triangulation usually runs with residuals of better than 2/3rd of GSD. This is a reliable and acceptable result. Following steps are stereo-editing of features for topographic and cadastral mapping, change detection and finally DTM extraction. Based on this, orthophotos can be produced and combined to a mosaic. These mosaics can be used for further analysis on land-use change and urban sprawl. Topological GIS analysis using overlay and intersection functions can highlight areas of rapid change and might be about illegal housing.

Such data can be used for the further planning, control of existing building sites and as basic information for the decision makers. Moreover, these data are important also for security reasons and might be the most important input of a successful city-planning and municipal management.

GIS is a central point in our daily spatial data management. GIS replaced the most paper maps and the transformation from Raster to vector data is in process. Some data will remain in raster format, these are mainly topographic maps and remotely sensed data e.g. satellite imagery and aerial images as orthophoto.

From beginning, the Bureau for Surveying and Mapping concentrated on small projects to get familiar with the technology. The medium format cameras are not really designed for missions over big areas since they need more photographs to cover huge areas than big format aerial sensors need. Various projects in very different scales/resolutions were performed within the last 2 years. Due to automation of the photogrammetric workflow, even projects with more than 220 km² have been managed successfully.
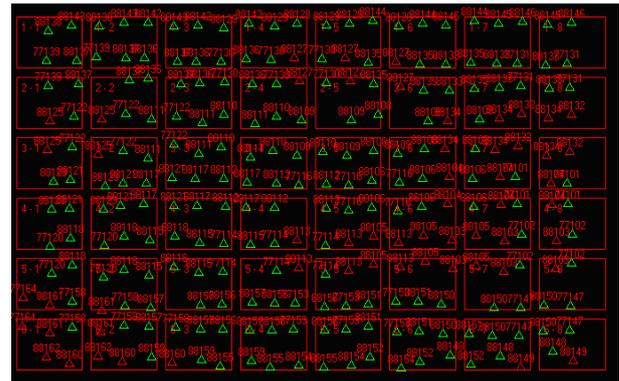
Figure 10: Scheme of a Tie- and Passpoint distribution for a small project during Automated Aerotriangulation

3.4 Validation of different scaling

The accuracy of the data after aero-triangulation depends on physical parameters as image-scale, Ground Sampling Distance, focal length and overlap. There are other parameters that have influence on the final quality as there are the quality of GCPs, their visibility and the number of tie-points. Redundancy in the AT gives the opportunity for blunder detection, which seems to be a key issue in the orientation process. To test the accuracy beside the resolution, two projects where done including an entire workflow. After AT, stereo editing and Orthorectification was done to create a complete product line. For this test, two missions were flown, one at 450m above ground that results in 6 cm GSD and at 1500m above ground that results in 20 cm GSD.

Mapping Scale 1:500	Mission 450 m above ground 6 cm GSD			
	ΔX in m	ΔY in m	ΔZ in m	
	<±0.221	<±0.160	<±0.190	max.
	<±0.089	<±0.089	<±0.099	average

Mapping Scale 1:2000	Mission 1500 m above ground 20 cm GSD			
	ΔX in m	ΔY in m	ΔZ in m	
	<±0.354	<±0.286	<±0.320	max.
	<±0.143	<±0.161	<±0.160	average

Table 1: Quality of the project after the AT

The table above delivers an interesting result. Even the GSD of 6 cm is pretty fine, this bigger scale does not deliver the quality of 2/3rd of a pixel, which is 4 cm. The average deviation is twice, only the accuracy in height is better than the expected 2*GSD which can be expected with 50 mm focal lens and 60% base lap in portrait format.

The lower scale mission with a GSD of 20 cm however fits nicely in the expectations and is even slightly better. Major problem is the visibility of the GCPs and the identification of the real centre on the 6 cm images. Beside that, the quality of the GPS measurement must be considered as not better than six cm. Due to the relatively small coverage of the big-scaled images, the chance to find good tie points in a geometric ideal position can cause problems. It means that the number of tie points is limited and blunders cannot be detected easily. On the small-scaled images, it is the other way round since the coverage is bigger. The number of GCPs per image is

increased and the position of the tie points follows better the ideal geometric distribution for a stabile adjustment.

The production of maps in scale 1:500 out of the 450m mission can be managed as long as additional ground data are integrated to increase the accuracy by redundancy. The relative accuracy is even better than the absolute one and some optimisations can be done to improve the complete product.
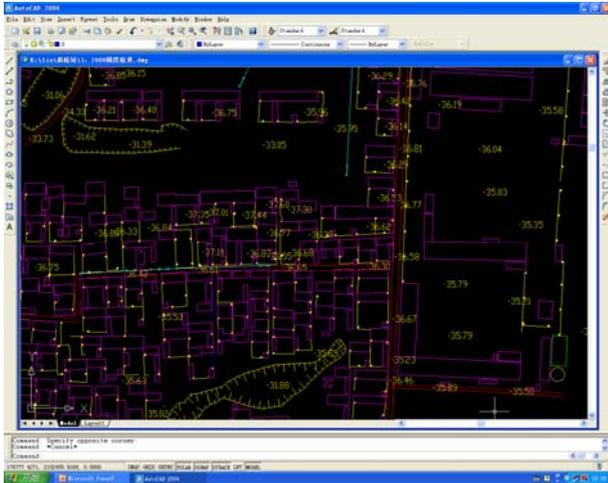
Figure 11: Digital map in scale 1:500 that has an accuracy between 5-10 cm

After automated DSM extraction and using the stereo-digitised map for break-lines, a refined DTM was generated and orthophots computed. These single orthophotos have then been colour-balanced, masked using seam-lines and finally combined to an orthophoto mosaic.

Figure 12: Orthophoto-Mosaic related to map-scale 1:500

The mapping in smaller scale is much easier since the quality of the AT for the 1200 m mission is fine. For map-scale 1:2000, we need an average accuracy of 20cm that we easily get with the ATed aerial data. Mapping in scale of 1:1500 would be possible as well. The screen-shot below shows

results of the Stereo-editing and feature extraction in CAD environment. This is a basis for cadastral mapping.
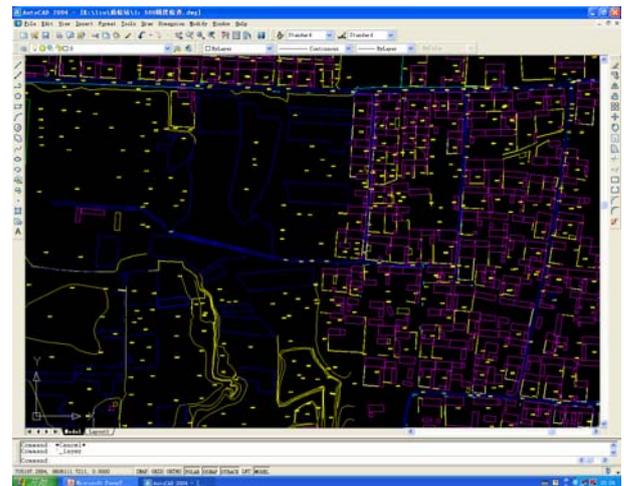
Figure 13: Digital map in scale 1:200 that has an accuracy between 15-20 cm

Feature extraction typically is a time consuming work that can get assistance only by a few software tools e.g. automatic height matching. Commonly, the editing is done in CAD environment to meet exactly the needs in mapping-design. This however limits the possibility to use GIS application for change detection.
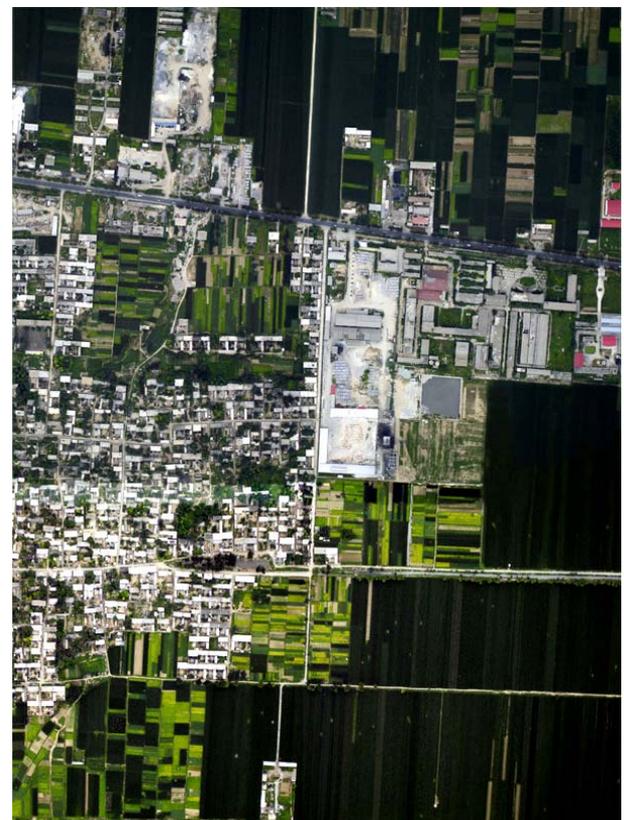
Figure 13: Orthophoto-Mosaic related to map-scale 1:2000

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