# AUTOMATIC DETERMINATION OF TIE POINTS FOR HRSC ON MARS EXPRESS

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**ABSTRACT:**

Within the scope of the "HRSC on Mars Express" mission the Institute of Photogrammetry and GeoInformation creates software for the automatic extraction of homologous image primitives from HRSC image data. With the obtained tie points a bundle block adjustment will be carried out with software developed at the Technical University of Munich which will result in an improved exterior orientation of the camera. With these results high level products like digital terrain models, ortho photos and shaded reliefs can be derived from the imagery.
So far the software, which is also capable of handling frame images, has been tested with MOMS-02/D2, MOMS-2P and HRSC-A data. This paper discusses the results and the achieved accuracy of the matching and the bundle adjustment with a selected MOMS-2P orbit and an HRSC-A dataset.

## 1. INTRODUCTION

On 02 June 2003 Mars Express was launched successfully at the Baikonur launch pad in Kazakhstan and the probe was placed into its interplanetary orbit. Mars Express will arrive at Mars on 25 December 2003. On board of Mars Express the HRSC Camera (**H**igh **R**esolution **S**tereo **C**amera) is mounted besides six other instruments and the Beagle 2 lander. The HRSC is a three-line scanner and will image large parts of the surface of Mars in colour and stereoscopically in high resolution. The HRSC model on Mars Express is a further development of the model which should have been used for the Mars 96 mission (Albertz et al., 1993) which unfortunately failed. Also an airborne version of the camera was build from the sparse model of the Mars 96 mission which is called HRSC-A (Wewel et al., 1998, Scholten et al., 2002). The Institute of Photogrammetry and GeoInformation creates software for the automatic extraction of homologous image primitives from HRSC image data. The software is based on earlier developments at the TU Munich.

The accuracy of the measured orbit of Mars Express around Mars will not be sufficient for the planned high level products such as digital terrain models, ortho photos and shaded reliefs. For this reason a bundle block adjustment will be carried out to achieve an improvement of the exterior orientation of the HRSC camera. For the orientation of the stereo images tie points are needed which should be extracted automatically from the planetary image data within this project. At the Institute of Photogrammetry and GeoInformation the software hwmatch1 is being adapted to meet the demands of the Mars Express mission. Hwmatch1 uses feature based matching and least squares matching techniques to extract tie points from three-line imagery. A detailed description of the functionality of hwmatch1 is presented in section 2. The software has been tested with MOMS-02/D2, MOMS-2P and HRSC-A imagery because today no planetary three-line imagery is available.

The MOMS-2P T08FE orbit has been picked for evaluation of hwmatch1 because a lot of ground control points (GCPs) are available for this dataset. The results of the matching and of the bundle block adjustment are presented in section 3. Besides this a HRSC-A dataset which was recorded over Duisburg has been evaluated. This dataset has been chosen to test the software interfaces and to test the software with HRSC imagery because the geometry of the HRSC-A camera is very similar to the Mars model. There are also plans to process whole blocks with about three image strips at once rather than single strips. So this test evaluates the results of hwmatch1 with HRSC data and the performance with more than one image strip. The results of the matching are described in section 4.

## 2. HWMATCH1

The image matching software hwmatch1 experienced quite a long evolution to the current state. The first version called ARO (**A**utomatic **R**elative **O**rientation) can handle two images (Tang, Heipke, 1996). An extended version of ARO was then developed which can handle more than two images. Also the possibility of calculating a bundle block adjustment was integrated (Heipke, 1997), this version is called framematch1. After that the software was adapted to the extended functional model of three-line imagery after Ebner et al. (1994) and the specific geometry (Brand et al., 1997). This version is called hwmatch1 (Brand, Heipke, 1998) and coexists with framematch1.

Hwmatch1 follows a coarse to fine strategy which means the matching result is refined step by step through image pyramids. The application flow is demonstrated in figure 1. As input data hwmatch1 needs the image data in VICAR (**V**ideo **I**mage **C**ommunication **A**nd **R**etrieval) or RAW format. The VICAR format is widely used in space projects and is also used during the Mars Express mission. The observed exterior orientation is read from an IBIS (**I**mage-**B**ased **I**nformation **S**ystem) file which is also a common binary file format used in space applications. There are also two mandatory files which contain the interior orientation and the calibration for each pixel. These files are created for each camera separately using data from the geometric calibration.

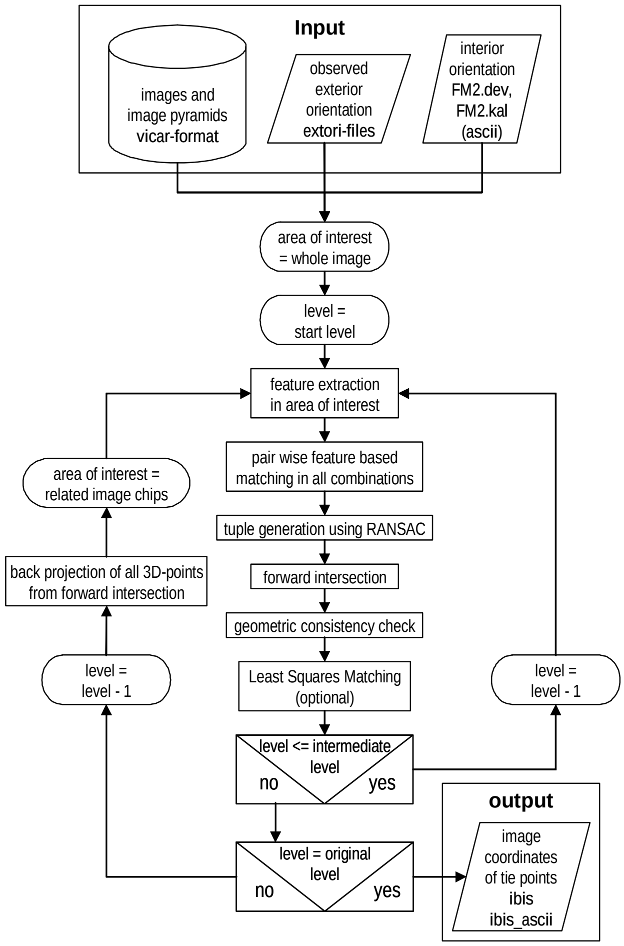


Figure 1: Application flow of hwmatch1

At the first stage hwmatch1 matches on the entire image and produces tie points via feature based matching. Point features are extracted using the Förstner operator (Förstner, 1986) and the images are matched pairwise in all combinations using the cross correlation coefficient as similarity measure. The tuples are generated with a RANSAC (**Ran**dom **Sa**mple **C**onsensus) algorithm (Fischler, Bolles, 1981) which is described further in Brand, Heipke (1998). To eliminate gross errors a geometric consistency check is done. A tilted plane is computed from all model points and their vertical distance to the plane is checked. If a point diverges from the average more than $3\sigma_0$ the tuple is omitted. This procedure is very handy in eliminating errors in the local neighbourhood.

Recently LSM (**L**east **S**quares **M**atching) was integrated into hwmatch1 following the approach of Krupnik (1994) and Krupnik, Schenk (1997). Because it is the most accurate matching technique available it is possible to further refine the result of the feature based matching. The tie points are matched in all images simultaneously and the final model points are calculated. They serve as an approximation for the reducing of the search space on the next pyramid level. At this time no bundle adjustment between successive levels is carried out which improves the values of the exterior orientation. Regarding the Mars Express mission such a bundle block adjustment may be necessary because the information about the orbit of the space probe will probably not accurate enough.

In hwmatch1 an intermediate level can be defined which is located between the top level and the level with the original resolution. Above this intermediate level the whole image is being processed and below the matching is performed only in image chips. This has the advantage that the complete image doesn’t has to be processed at the larger pyramid levels which saves a considerable amount of computing time. This means that corresponding points are searched in areas only where points have been found before due to good texture. If the final level is reached the found tuples are written to an IBIS file which serves as input for the bundle block adjustment.

## 3. MOMS-2P

During the MOMS-2P/Priroda mission, launched in April 1996, the Modular Optoelectronic Multispectral Stereoscanner MOMS-2P acquired digital high resolution, along track, threefold stereoscopic and multispectral imagery of the Earth's surface from the Russian space station MIR. The MOMS-2P/Priroda mission was the second use of the MOMS in space after the successful MOMS-02/D2 experiment in 1993.

The photogrammetric processing of the MOMS-2P/Priroda data was conducted by several German university institutes and the DLR - Remote Sensing Technology Institute. The major aim was the realisation of the entire photogrammetric processing chain, which starts with image correction and ends with the generation of digital terrain models (DTMs) and ortho photos.

The entire processing chain is described in Kornus et al. (1999a). Data of the three strips T083C, T08C5 and T08FE are used for geometric inflight-calibration and the sensor orientation by photogrammetric block adjustment. In addition a digital terrain model is derived. The comparison with a reference DTM of superior accuracy showed unexpected systematic undulations in the MOMS DTM. The height accuracy was about 8 m. These results were improved by Müller et al. (2001) by introducing more ground control points (GCPs) and choosing a smaller distance of orientation images (DOIs) of 70 image lines. The undulations mentioned above weren’t present.

The Mode D data take T08FE is recorded from an ascending orbit, crossing the ground tracks of T08C5 and T083C to the west of Lake of Constance and north of Munich. The strip of T08FE (scenes #17 - #23) evaluated here contains 40741 image lines corresponding to approximately a strip length of 700 km with a swath width of 100 km. The ground pixel size of the imagery is 17.1 m at 377 km orbit altitude.

Kornus et al. (1999b) describe the lower accuracy of the exterior orientation parameters of the orbit T08FE, which is reflected in large bias estimates in their bundle block adjustment. Therefore better approximate values of the exterior orientation parameters are determined in a separate preprocessing step.

First of all the MOMS images were converted into VICAR format and the orientation data and additional information were made available in the specific formats (calibration data or IBIS data). The matching of the seven scenes is done using a standard parameter set, which is characterised by the following: start-level 4, intermediate-level 2, Förstner parameter roundness 0.9, threshold of the correlation coefficient for pairwise point matching 0.73, image chips for the LSM 25x25 pixels. Similar parameters are used by Gruen, Zhang (2003).

At the beginning (scene #17) and at the end (scene #23) of the orbit T08FE only 2-ray points could be determined. Furthermore the matching is influenced by the appearance of many clouds in the scenes. The point distribution at the original image resolution is the following:

| ***Scenes*** | ***Lines*Samples*** | ***2-ray*** | ***3-ray*** |
|---|---|---|---|
| 17 | 5920*5800 | 1589 | - |
| 18 | 5920*5800 | 866 | 1249 |
| 19 | 5920*5800 | 1015 | 1162 |
| 20 | 5920*5800 | 1808 | 710 |
| 21 | 5920*5800 | 769 | 1587 |
| 22 | 5920*5800 | 2311 | 526 |
| 23 | 5920*5800 | 1719 | - |

Table 1: Point distribution of the matched T08FE orbit.

In a first step blunders (2270 of 15311 homologous points) are eliminated after a bundle block adjustment. In the next step adjusted orientation parameters are calculated by another bundle block adjustment.

The bundle block adjustment is done with a prerelease of the software hwbundle (Spiegel et al., 2003), which is based on the principle of orientation images (Kornus, 1999). The tie points, which were found by hwmatch1, are introduced as observations with a standard deviation of 0.3 pixels. The orbit and attitude data of the exterior orientation were processed by the German Space Operation Center (GSOC) of the DLR. This resulted in positional data with a relative accuracy of 1 m and an absolute accuracy of 30-50 m. Therefore the bias of the positions was set to 0 m with a standard deviation of 30 m. No drift parameters for the positions are considered. For the attitude data the relative accuracy was set to 1 arcsecond and the attitude angles bias, linear and quadratic drifts were introduced as free unknowns. 218 ground control points (GCPs) were measured by the DLR in 1:50000 (SX = SY = 20 m, SZ = 5 m) and in 1:25000 (SX = SY = 15 m, SZ = 5 m) topographic maps. The points were measured in one channel (MOMS channel 6) and were transformed into the other channels by local least squares matching. Their standard deviation was set to 0.3 pixels. Only 60 GCPs were introduced into the bundle block adjustment. The remaining points deal as independent check points. The distribution of the tie points and the GCPs is shown in figure 2. In cloudy areas and on the lakes no tie points were found.

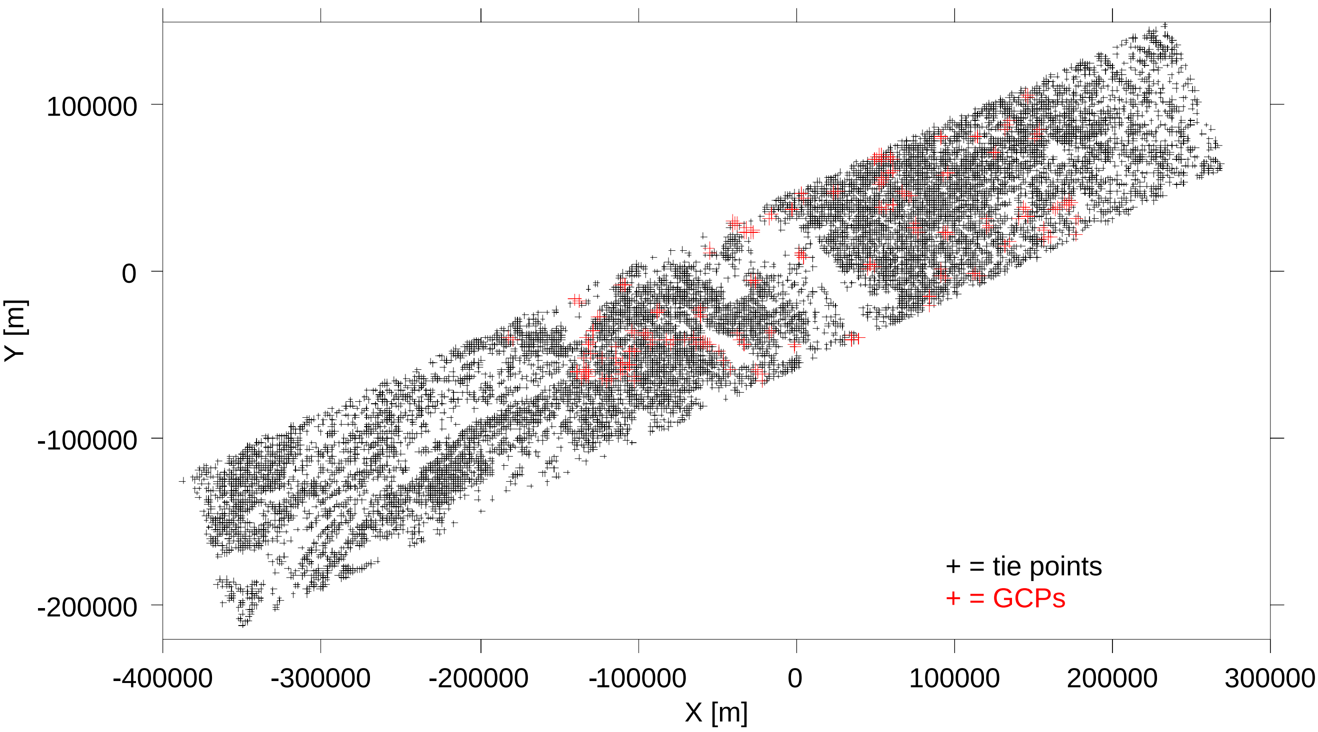


Figure 2: Plot showing the distribution of the tie points and GCPs of T08FE.

The results of the empirical standard deviations calculated at 158 check points are shown in table 2. In this step the calculated coordinates of the GCPs from the bundle block adjustment were compared to the values from the map. The standard deviation lies in the subpixel range.

| | *SX [m]* | *SY [m]* | *SZ [m]* |
|---|---|---|---|
| 60 GCPs | 13,3 | 16,9 | 7,6 |

Table 2: Empirical standard deviations at 158 independent check points.

In addition a bundle block adjustment similar to Müller et al. 2001) was calculated. In this case 207 GCPs and no independent check points were introduced into the bundle block adjustment. The RMS values at the GCPs were determined and listed in table 3.

| | *RMS of GCP correction* | | |
|---|---|---|---|
| | **X [m]** | **Y [m]** | **Z [m]** |
| Müller et. al 2001 | 7,9 | 12,9 | 1,4 |
| 207 GCP | 7,7 | 8,5 | 0,9 |

Table 3: Root mean square differences of the GCPs.

Although the values presented in table 3 should not be interpreted as independent figures, they demonstrate that the results obtained from the matching are comparable to the results of Müller et al. (2001). The independent check reveals especially in SZ a significant deviation to the results shown in table 3. The processing of the MOMS-2P data shows that one aim of the matching, the delivery of high quality homologous points for the bundle block adjustment, which should compute an improvement of the exterior orientation of the camera, could be fulfilled.

## 4. HRSC-A DUISBURG

This dataset was recorded on 01 September 1998 over Duisburg-Grossenbaum by the BKG (Bundesamt für Kartographie und Geodäsie) and the DLR (Deutsches Zentrum für Luft- und Raumfahrt e.V.). Four image strips were flown in east west direction and there is also a cross strip available which was however not used. Strip no. 03 has been omitted too due to gross errors in the imagery but this doesn't pose a problem because the strips have a very large cross overlap. The analysed block therefore consists of three strips which are about 9000 lines long each. For the matching the nadir and the two stereo channels were used. The flying height was at about 2500 m resulting in a pixel size on the ground of about 20 cm. The covered surface is an urban area with nearly no changes in elevation except for the buildings and the trees. Due to flight turbulences distortions exist in the raw imagery (figure 3).

The matching was carried out on the original level2-data which means no geometric corrections have been applied to the imagery prior to matching. It should be noted that this sequence of processing doesn't imply a suggestion to do matching on raw aerial three-line imagery. The reason for our processing chain was that we do not have a rectification module available. During the Mars Express mission no such distortion of the image data will occur. Since the minimal flying altitude of the space probe will be about 350 km above the surface and the Martian atmosphere is very thin the space probe won't be exposed to turbulences like here on earth

Figure 3: A display detail of an HRSC-A image showing heavy distortion.

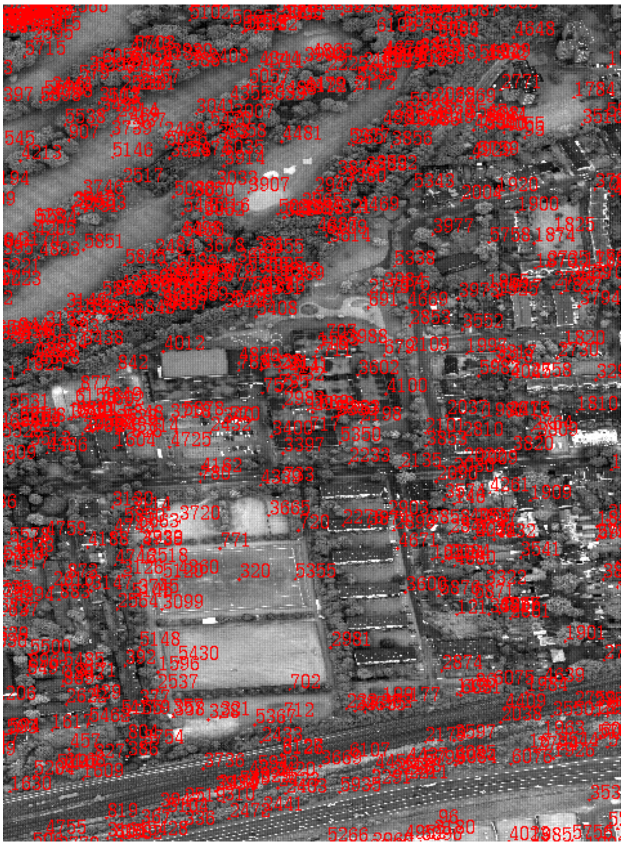

Figure 4: Distribution of the tie points on a display detail of one image (north is left).

The result of the matching shows an equal distribution of the tie points over the whole block as shown in figure 5. A closer look reveals that there are some areas with a higher density of tie points and some areas which lack tie points. For example in the northwest there is a hole and the area is only covered by two images. It turns out that in one of these images there is heavy distortion similar to the one shown in figure 3. In the middle of the block an incised line can be discovered. This is a railroad next to a large street (figure 4) which both prevent the finding of accurate tie points presumably because of their repetitive patterns. Next to that railroad and the street a sports field can be found. Hardly any tie points were found on the playing field which has very low texture but this was to be expected. In the northeast the tie points form the outline of the golf course with a very low quantity of tie points on the fairway and many tie points in the trees.

After the matching a bundle block adjustment has been carried out with the software hwbundle. This piece of software is based on CLIC (Kornus, 1999) and is also being adapted to the special requirements of the Mars Express mission at the TU Munich (Spiegel et al., 2003). In the whole block a total of 32 GCPs are available which were measured with GPS. No robust adjustment has been carried out but 21 points with large residuals were manually eliminated. The adjustment yields a theoretical standard deviation of SX = 0.12 m, SY = 0.12 m and SZ = 0.42 m. Though no independent checks could be carried out the result can be considered as very good because the achieved standard deviation lies in the subpixel range. The value of SZ is a little bit higher but there are a lot of tie points in the trees which are difficult to match and to evaluate if they are right or wrong.

## 5. CONCLUSIONS

This paper presented the performance of the software hwmatch1 which will be used during the Mars Express mission to automatically derive tie points from the imagery of the HRSC camera. Two test results with MOMS-2P and HRSC-A imagery were shown. Concerning the test with the MOMS imagery, the comparison of our results with the adjustment of Müller et al. (2001) shows a similar accuracy at the GCPs. Hwmatch1 delivers correct tie points to improve the exterior orientation of the MOMS camera. The test with the HRSC-A imagery shows that hwmatch1 also delivers high quality tie points with challenging aerial three-line imagery. The standard deviations of the object points remain below the ground resolution.

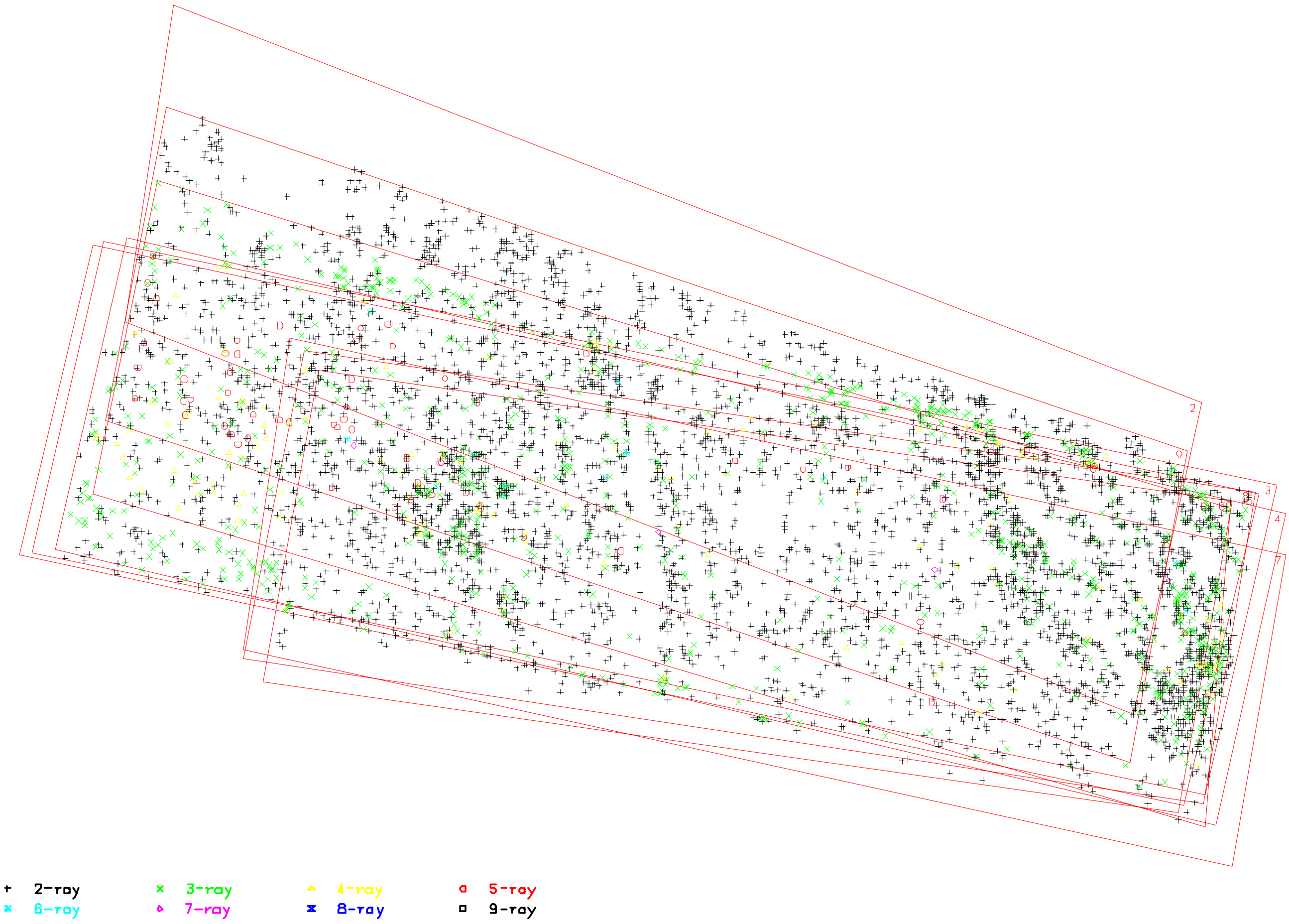


Figure 5: Distribution of the tie points of the HRSC-A block Duisburg (north is up).

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