

GENERATION AND UPDATE OF VMAP DATA USING SATELLITE AND AIRBORNE IMAGERY

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ABSTRACT

In this paper we report on the results of two projects conducted recently for the AMilGeo (Amt für Militärisches Geowesen) of the German Federal Armed Forces. The aim of the first project was to establish an operational workflow to update existing VMap Level 1 data using commercially available satellite imagery. The complete workflow, primarily based on Intergraph software, was tested successfully with several examples and integrated into the existing VMap1 production environment. Additional software was developed for the feature linking of the "old" VMap1 data and the "new" topographic features extracted from the satellite images. The second project was a study focused on the generation and update of VMap Level 2 data using both satellite and airborne imagery. It was investigated in detail, which VMap2 features can be extracted from different satellite and airborne imagery by a human operator.

1 INTRODUCTION

The Vector Smart Map (VMap) family of databases (see Table 1) is a set of digital vector product databases used for military IT-, simulation- and geoinformation systems as well as for the production of military analogue and digital maps. VMap Level 1 (VMap1) data correspond to the geometry and contents of maps in the scale of 1:250.000, the VMap Level 2 (VMap2) database contains information roughly equivalent that of maps in the scale of 1:50.000. The VMap1 and VMap2 databases consist of natural and man-made point, line and area objects subdivided into the following 10 feature classes (called "themes" or "coverages" in VMap terminology; NIMA 1993, 1995): Boundaries, data quality, elevation, hydrography, industry, physiography, population, transportation, utilities and vegetation. The VMap family is completed by the low resolution VMap Level 0 (VMap0) and the high resolution Urban VMap data.

| Product Level | Equivalent Map Scale | Status |
|---------------|----------------------|---|
| VMap Level 0 | 1:1.000.000 | Available world-wide as the DCW (Digital Chart of the World), 2 nd ed. |
| VMap Level 1 | 1:250.000 | Available world-wide in 2001 |
| VMap Level 2 | 1:50.000 | Produced on request only |
| Urban VMap | City Maps | Produced on request only |

Table 1. The VMap family of databases and their status of availability

Sources of VMap are analogue topographic and thematic maps, image data and national databases. The VMap data are stored in the *Vector Product Format* (VPF) according to specification MIL-STD-2407 of the U.S. National Imagery and Mapping Agency (NIMA, 1996) which is a subset of the Digital Geographic Information Exchange Standard – Feature Attribute Coding Catalogue (DIGEST-FACC). The VMap1 database is being populated in a co-production of the different NATO nations. The VMap1 production in Germany began in 1996 and will be finished in 2001. Since the sources of VMap1 are already several years old, the revision of the VMap1 data is becoming more and more important. The VMap1 data have a horizontal / vertical accuracy of 125m / 20m in most parts of the world. VMap2 data are produced on request, mainly for current crisis regions. The VMap2 data have a horizontal / vertical accuracy of typically 25-50m / 10m. Only a few VMap2 data sets are available up to now. In future, VMap2 data will be replaced by *Foundation Feature Data* (FFD, 1998) which is, however, rather similar to VMap2.

In the past, several investigations have been performed to analyse the potential of satellite imagery for the population and update of topographic databases, see e.g. Busch (1998), Dowman (1998), Jacobsen et al. (1998) and Ridley et al. (1997). This paper reports on results obtained during two projects conducted for the AMilGeo (Amt für Militärisches Geowesen) of the German Federal Armed Forces. The aim of the first project was to establish an operational workflow to update existing VMap Level 1 data using commercially available satellite imagery. The second project was a study focused on the generation and update of VMap Level 2 data using both satellite and airborne imagery. Chapter 2 takes a look at the analysis and assessment of different satellite sensor systems for the extraction of VMap1 data. The investigation of the potential of satellite and airborne sensor systems for the extraction of VMap2 data is subject of Chapter 3. Chapter 4 describes the methods applied for VMap1 feature extraction and update. Finally, conclusions are drawn and an outlook on future work is given.

2 ANALYSIS OF SATELLITE IMAGERY FOR VMAP1 DATA EXTRACTION

2.1 Input Data

The first task in the project was to analyse and assess the potential of different sensor systems for the extraction of VMap1 data. For our investigations we used several satellite images from two test sites located in Cologne, Germany, and Minsk, Belarus (see Table 2). The optical images were acquired in panchromatic as well as multispectral bands, and a number of SAR images were also available.

| Test area | Landsat TM (30 m) | SPOT | | IRS-1C | | ERS-1 (30 m) | JERS-1 (18 m) | Radarsat (28 m) |
|-----------|----------------------|------------|-----------|-----------|-------------|-----------------|------------------|--------------------|
| | | PAN (10 m) | XS (20 m) | PAN (6 m) | LISS (23 m) | | | |
| Cologne | X | X | X | X | X | X | - | X |
| Minsk | X | - | X | X | X | - | X | X |

Table 2. Images used for VMap1 feature extraction

2.2 Visibility of VMap1 Features in Satellite Imagery

The visibility of the VMap1 features from the satellite imagery was established by a human operator according to specification MIL-V-89033 (NIMA 1995) for the VMap1 database. It consists of 10 themes ("coverages") with 169 features. Our test sites contain 103 VMap1 features with a large amount of man-made features (60%). These 103 features can be subdivided according to the feature type into 27 area features (26%), 29 line features (28%), and 47 point features (46%). It should be noted that according to the VMap2 definition, some features can have different types depending to their size.

Table 3 presents the results of the image interpretation. In the table the total number of VMap1 features which could be identified in any of the satellite images of both test sites is given. From the 103 features 53, or 51%, could be found. This value indicates that other sources (e.g. images of higher resolution) and methods (e.g. field survey) are required in addition to satellite imagery to comprehensively update VMap1. It can also be seen in Table 3 that more than $\frac{3}{4}$ of the area features were identified, whereas 55% of the line features and only 34% of the point features were detected. The definition of point features in the VMap1 database is rather inhomogeneous with respect to their size. Point features range from 15 cm up to 600 m in diameter. As a result, point features are often either not distinguishable or not significantly detectable due to the moderate image resolution. When going through the list of identified features it was found that the most important features like roads, rivers, built-up areas, cropland and grassland, could be identified in at least some of the satellite images.

| | Available features [#] | Identified features [#] | Identified features [%] |
|--------|------------------------|-------------------------|-------------------------|
| Areas | 27 | 21 | 78 |
| Lines | 29 | 16 | 55 |
| Points | 47 | 16 | 34 |
| Total | 103 | 53 | 51 |

Table 3. Number of VMap1 features identified by an operator in all satellite images

The degree of feature identification of the different sensor systems is depicted in Figure 1. The figure shows very clearly that the number of identified features increases with better resolution of the satellite imagery. Satisfactory results were achieved with IRS-1C using the high resolution panchromatic channel in combination with the multispectral LISS channels. Landsat TM provided fair results due to the missing high resolution channel in the panchromatic band. It can also be seen that the SAR images from ERS-1 and Radarsat are well suited for visual feature extraction.

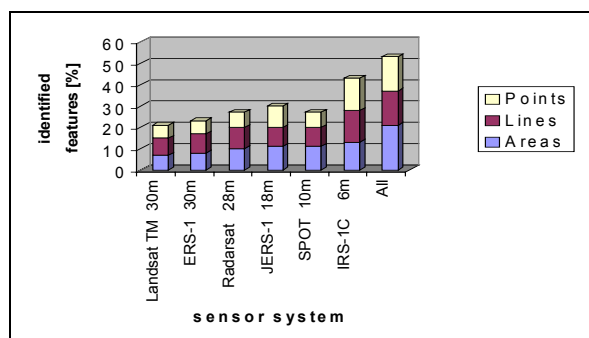


Figure 1. Identified VMap1 features in % of all 103 available features in both test sites

3 VISIBILITY OF VMAP2 DATA IN AERIAL AND SATELLITE IMAGERY

3.1 Examination of VMap2 Feature Catalogue

The aim of the first step of the VMap2 project was to determine which features from the VMap 2 catalogue could possibly be extracted automatically from images in general. Only the identification of features was examined, feature attributes were not considered. The examination was carried out by a photogrammetric operator with a wealth of experience in interpreting aerial imagery, mostly from areas in Germany. She investigated the VMap2 catalogue without reference to any specific imagery. The examination was performed in three steps. In every step all features from the catalogue which fulfilled certain constraints were extracted. In the further steps more stringent constraints were applied which led to a smaller group of features.

The first, very obvious constraint was that the feature has to be visible from the air. This constraint is fulfilled if the feature is not hidden by other features. Features which can be both, visible and hidden (e. g. a road which is usually visible, but hidden in a forest), were considered as visible. Further constraints in this step were that the features must have a permanent geographic position (which rules out cars etc.), and that it must be possible to directly recognise the feature. Therefore, e. g. a tunnel was not considered as visible because the recognition is only possible by identifying the entrance and exit, not the tunnel itself. In the second step only features were kept on the list which could be unambiguously identified by an experienced human operator when inspecting only the feature and the immediate neighbourhood. Thus a telecommunications building was not considered, because whereas a building can be easily recognised, in most cases its use cannot be unambiguously determined. In the last step only features which could possibly be extracted automatically from images given the current state in automatic image analysis were further considered.

Figure 2 shows the result of the investigation. In this figure the results are depicted graphically divided into feature types and thematic coverages. 100% corresponds to the number of features in the complete VMap2 catalogue, i. e. 177. The result shows that although over 70% of the features are visible and 45% can be detected by an experienced human operator only about 6% can possibly be extracted automatically. In these 6% however, some of the more important features such as roads which also appear more often than other features are contained. A second result is that area features have the highest share followed by line and point features in each of the three graphs. The coverage in which the most features are visible and can be recognised is the population coverage, followed by hydrography, industry, and transportation. In the hydrography coverage the most features can possibly be extracted automatically.

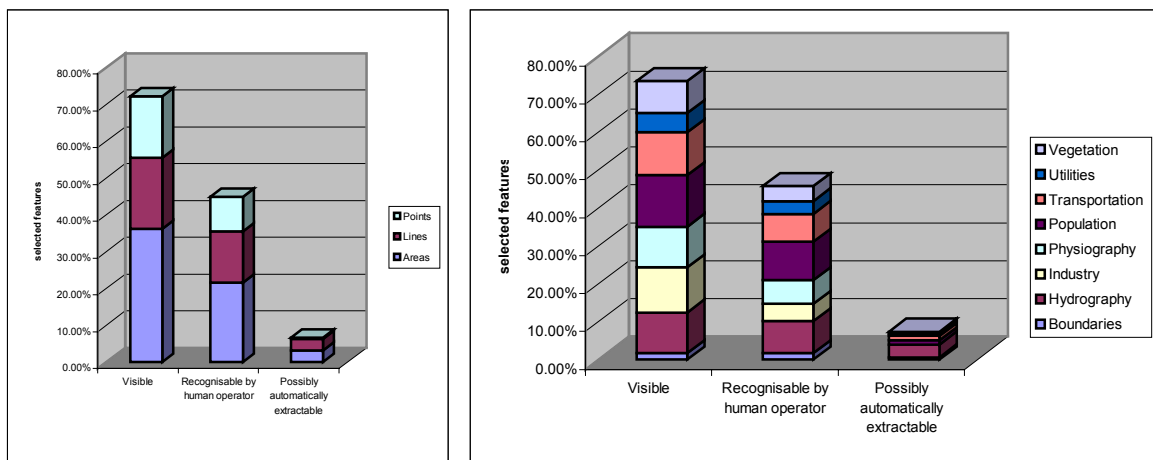


Figure 2. Selected VMap2 features subdivided into feature types and thematic coverages

3.2 Analysis of Satellite and Airborne Imagery for VMap2 Data Extraction

Based on the results of the last section the potential of satellite and airborne imagery for detection and recognition of VMap2 features was examined. We used two test sites: Bückeberg in Germany and Sarajevo in Bosnia-Herzegovina. As input data we chose images from different sensors with different resolutions: Landsat TM, SPOT XS, SPOT PAN, DPA MS, panchromatic and colour aerial images (see table 4 for test site and ground pixel size).

According to STANAG 3769 (1998) the definition of detection is: “In imagery interpretation the discovering of the existence of an object, but without recognition of the object”, the definition of recognition is: “The ability to fix the identity of a feature or object in imagery within a group type”. These definitions are somewhat problematic because a distinction between recognition and detection during image interpretation is very difficult to achieve. It also implies that recognition requires detection. We tried to approach this issue by separating our work into two steps.

In the first part we examined recognition. Experienced photogrammetric operators tried to find the features from the list of features, which can be recognised in general (see section 3.1) within the sensor images. First they worked on low resolution sensor images and went on with higher resolution. The reason for this sequence was to avoid the memory effect. This effect can lead to the recognition of a feature, which is only detectable, simply because it was recognised in some other imagery beforehand. With the assumption that features which were recognised in low resolution images can also be recognised in higher resolution images this effect can be at least partly alleviated. In the second part we examined detection. Because the detection of a structure in an image does not lead directly to the feature without recognition, a comparison with reference data is necessary. We exploited the high resolution images with the recognised features as reference and searched for these features in the lower resolution images. Features, which were recognised only in the high resolution images but show a special geometric and radiometric structure in lower resolution were declared detectable. For the test site Bückebug we used the DPA and the aerial images as reference and for Sarajevo the aerial images. Table 4 shows the number of features of the most important VMap2 coverages which can be detected (left) and recognised (right) in different sensor images. The number of detected and recognised features is only valid for our test sites. They do not necessarily show the potential of the sensor for all VMap2 features because not all feature of the catalogue were included in our test sites. As depicted the most features which can be recognised in both low and high resolution data are those from the transportation coverage. The highest difference between feature recognition in high and low resolution images can be found for features of the population coverage.

| | Landsat TM | SPOT XS | SPOT PAN | DPA MS | Aer. Im. Pan. | Aer. Im. RGB |
|----------------|----------------|----------|----------|----------|---------------|--------------|
| | Bückebug./Sar. | Bückebug | Sarajevo | Bückebug | Sarajevo | Bückebug |
| | 30m | 20m | 10m | 0.8m | 0.6m | 0.5m |
| Hydrography | 3 2 | 3 2 | 1 1 | - 2 | - 1 | - 2 |
| Industry | 1 0 | 1 0 | 2 1 | - 2 | - 2 | - 3 |
| Population | 2 1 | 1 0 | 5 3 | - 6 | - 5 | - 7 |
| Transportation | 6 5 | 5 5 | 8 6 | - 7 | - 8 | - 6 |
| Vegetation | 3 2 | 4 2 | 3 3 | - 4 | - 2 | - 3 |

Table 4. Number of VMap2 features which can be detected (left) and recognised (right) in different sensor images. For DPA and the aerial images no detection figures were determined, since these sensors served as reference data (see text)

4 METHODS FOR VMAP UPDATE

4.1 General workflow

The overall workflow of the feature extraction and update procedure is shown in Figure 3. Data pre-processing involves the radiometric enhancement and the geocoding of the images. Feature extraction from the images can be carried out interactively or supported by automation. For the VMap1 data we used supervised maximum-likelihood classification for most area features (see section 4.2 below) followed by raster-vector-conversion, and mainly interactive methods for line and point features. For VMap2 the described approach will be extended to include some more automatic methods of feature extraction. The feature attributes are assigned interactively in the current version of our system. Within the GIS validation process complex polygons are resolved and the data structure of all features and attributes is checked. The core of the update procedure is a feature linking process of the "old" VMap data and the newly extracted topographic features. This process determines the likeness of linked or non-linked features based on geometry, feature class, attributes and topology. The result of the update procedure is a revised VMap data set. In the following the feature extraction and the actual update are discussed in more detail.

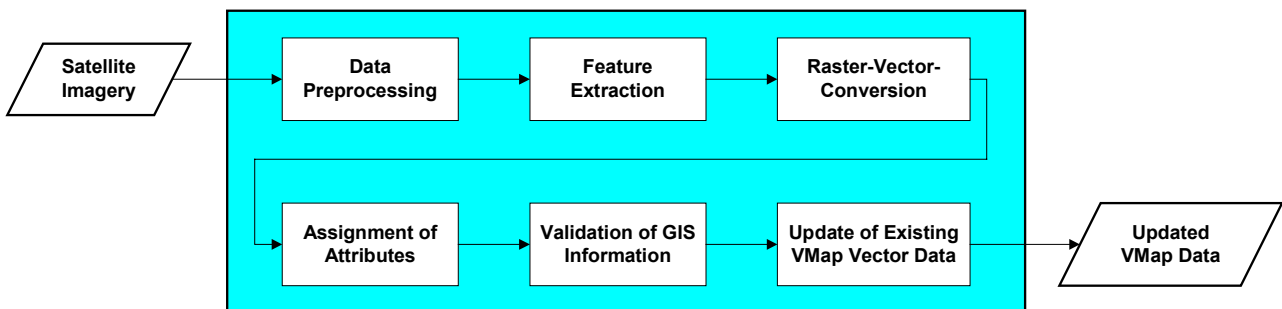


Figure 3: Overall update workflow for VMap data

4.2 Feature extraction

As mentioned we used supervised maximum likelihood classification, included in many commercial GIS and image processing systems, for automatically extracting area features. For the extraction of the line and point features standard interactive methods were applied.

For the multispectral classification investigations were first performed to establish the optimal band combination. Good results were achieved with the 4 spectral bands IRS-1C 3+4 and Landsat TM 1+5. Increasing the number of spectral bands and/or adding SAR information to the classification process could improve the results only locally. The classification itself was carried out by first choosing training areas for five different classes, followed by a maximum-likelihood classification and an unsupervised classification by K-Means clustering for each resulting class separately. Finally, another multispectral classification was performed.

In the final processing step all extracted area, line and point features were validated. To this end, all features and attributes were checked, and complex shapes were resolved. All data entries which were detected as errors were written into a list file and can be corrected interactively by the user. The result of the feature extraction process is a verified vector data set. The geometric information of the vector data is stored in MicroStation Design (DGN) files (one DGN file for each theme), whereas a relational ORACLE database contains the attribute information.

4.3 VMap update

Figure 4 provides an overview of the VMap update workflow. It consists of four parts (sub-workflows) that incorporate newly extracted data into existing VMap data (Intergraph 1998). Each part utilises a combination of automated and interactive process steps to modify, integrate and update the data.

During the **feature extraction preprocessing** the newly extracted features from individual theme-based DGN files are converted into an object-oriented GIS environment (object space) based on a FACC data dictionary. In addition, subsequent process steps modify and validate the data for compliance with the feature/attribute content of the VMap product specification.

The **VMap preprocessing** starts with the conversion of the existing VPF data into an object space environment. Subsequently, the data are converted to a common resolution to match the newly extracted feature data. The structure of the data is then converted to a FACC data dictionary.

The **merge resolution** step is the focal point in the update workflow. All input data has been pre-processed and the determination which features to incorporate into the new updated object space can be performed. To accomplish this task, the sub-workflow incorporates a combination of six automated and interactive process steps that provide the capability to link, integrate, attribute and update existing VMap data with newly extracted feature data.

The **VPF production workflow** is the last step of the VMap update workflow. The majority of the process steps contained in this part are involved in modifying the structure of the data and not in manipulating feature topology. This sub-workflow focuses on converting the updated data to its specific VPF format. To accomplish this transition, the data are processed from individual theme-based object spaces into an integrated environment, and then back out to individual theme-based DGN files, before writing the data out in the VPF format. The final output from the revision workflow is an updated VMap dataset in VPF format.

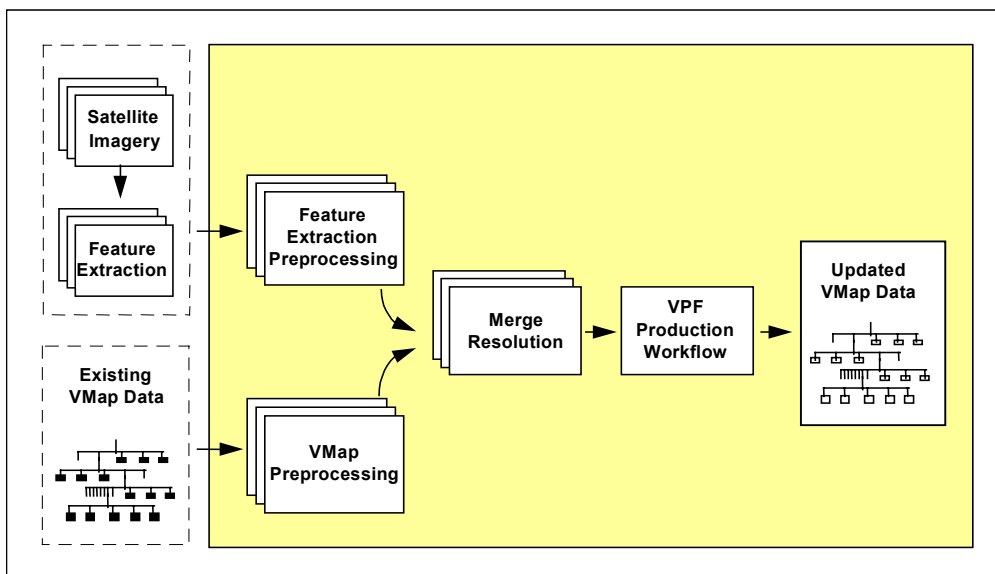


Figure 4. Detailed workflow for VMap update

In the following the **feature linking process**, which is the newly designed part of the merge resolution sub-workflow, is described in more detail. The feature linking process provides the capability to automatically identify or link “like” features from two disparate data sets. Once features are linked, a decision can then be made as to which features to retain in the data set and which features to exclude. The linking process is predicated on a series of feature, attribute and geometry tests which output a degree of certainty that the linked features are a match. A resulting “linked” queue is output from this process, as well as an “unlinked” queue which identifies features that could not be matched during processing.

The final determination of which features to retain in the data set is strictly a decision by the human operator. Based primarily on the certainty value of linked features, he can copy features from the linked or unlinked queues into the active object space. Various editing tools can be used in this process to ensure feature connectivity and accuracy.

The calculation of the certainty value is based on a series of tests:

- Feature geometry: are the features of the same type (area, line or point)?
- Feature class: are the features identical or similar?
- Attributes: are all, some or none of the attributes the same?
- Topology: how well do the features relate to each other?

The feature type being queued (i.e. point, line or area) determines how features are linked. Point features are linked on a one to one basis, that is, every queued point feature will only be linked to the highest certainty value rated point feature. The geometry test is based on a radial search. Linear features are linked in a different manner. A queued linear feature can be linked to more than one feature, however, if multiple links are made then each link will be handled as a separate queued entry. The geometry test is based on distance and topology. Lastly, area features are linked in yet another manner, whereby each queued area feature can have multiple links with all links processed and displayed on one queue. Here the geometry test is based on the overlap between the features.

4.4 Implementation issues

The complete workflow was tested successfully with several examples and fully integrated into the existing VMap1 production environment. The workflow is based on INTERGRAPH software under WindowsNT. For the feature extraction, the modules *Image Analyst*, *MGE*, *I/GEOVEC* and *I/RAS B* were used, the update part makes use of *Dynamo* and *VPF*. New software was developed for the feature linking. The update part of the workflow is based on Intergraph's object-oriented *Dynamo* software. This sub-workflow makes use of automatic queued and interactive edit functionality.

5 CONCLUSIONS

The following are experiences made during the execution of the projects:

- Aerial and satellite imagery is well suited to extract and update VMap features. For VMap1 satellite imagery is sufficient in general, for VMap2 aerial imagery is mandatory.
- The geometry of some of the area features could be extracted automatically, the extraction of the line and point features as well as the assignment of the features and their attributes related to the VMap structure has to be done interactively.
- In order to increase the number of features which can be extracted automatically, more research and development is necessary. Methods for processing airborne imagery (0.2 – 1 m resolution) and satellite imagery (5 – 30 m resolution) should be combined (see e. g. Straub et al., 2000).
- Refined methods for SAR image processing are needed.
- The update part with the semi-automatic feature linking is comfortable and user-friendly.

The developed workflow was accepted by the customer and will be applied in practice for the systematic VMap1 update. It can be adapted to the recent and forthcoming very high resolution satellite imagery of Ikonos 2, OrbView-3 and Quickbird.

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