# Multi-sensor remote sensing for military cartography

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## 1. SUMMARY

We have studied remote sensing data from sensors in different wavelength regions (optical, thermal infrared and microwave) and from different platforms (airborne and spaceborne) in order to extract geographical information. By comparing the extracted information with an existing geographical database of a test area in the Netherlands we find that to obtain military relevant cartographic information from remote sensing images resolutions of 5 meter or less are required. For appropriate classification of extended objects like agricultural fields multi-layer imagery is necessary.

## 2. INTRODUCTION

Due to the changing international situation after 1989 the tasks of the Royal Netherlands Army (RNLA) have changed considerably. Nowadays the RNLA considers and carries out operations outside the actual NATO area contrasting the situation during the Cold War. For NATO areas geographical information is sufficiently available and in case of allied operations this information is shared. For many other parts of the world geographical information is often sparse, and for non-NATO operations like UN operations each country is responsible for its own intelligence. In this context an independent and accessible source of geographical information is a necessity. Remote sensing data from satellites, but also from aeroplanes, UAV's, etc., offer such a source for geographical information.

The goal of the study presented here is to evaluate the potential of remote sensing for geographical information extraction. The extracted information can then be used to update outdated maps or to obtain basic information about an unknown site.

For this study we have collected remote sensing data from sensors in different wavelength regions (optical, thermal infrared and microwave) and from different platforms (spaceborne as well as airborne). The data have been collected for two test sites showing a variety of geographical features.

One test site is located in the Netherlands and shows no significant relief. It is called the 'Heerde' test site after the Dutch topographical map, which contains the test site. For this test site a digital geographical database is available, so that a detailed comparison between the remote sensing data and the geographical database is possible.
A complete collection of remote sensing images consisting of spaceborne TM, SPOT, KVR, ERS, JERS, and airborne CAESAR (optical, multi-spectral), PHARS (microwave , C-band) and TIR data is available.

The second test site, located in Germany, near Freiburg, comprises part of the Rhine Valley and the Black Forest showing moderate relief up to 1500 meter. For this site, called the Freiburg test site, TM, SPOT, ERS, JERS and KVR data, including a DEM (DTED) are available. In a following study it will be used to investigate the influence of relief on remote sensing images and the generation of a digital elevation model (DEM) from these images.

## 3. THE REMOTE SENSING DATA

### 3.1 Heerde test site

This test site is located on the TDN topographical map 27. The actual test site is oriented exactly east-west. and comprises an area of 10 by 20 km between the river IJssel and the Holterberg to the North of the city Deventer. The location is given by RD co-ordinates (x,y) 200000, 477500 m (South West corner) and (x,y) 220000, 487500 m (North East corner).
Low resolution satellite remote sensing data are available for the whole of map 27 East and West (RD 180000,475000 (South-west), RD 220000,500000 (North-east)), while high resolution airborne data are only available for the actual test site.
The test site includes the IJssel and its inundation (uiterwaarden) and shows landscapes like

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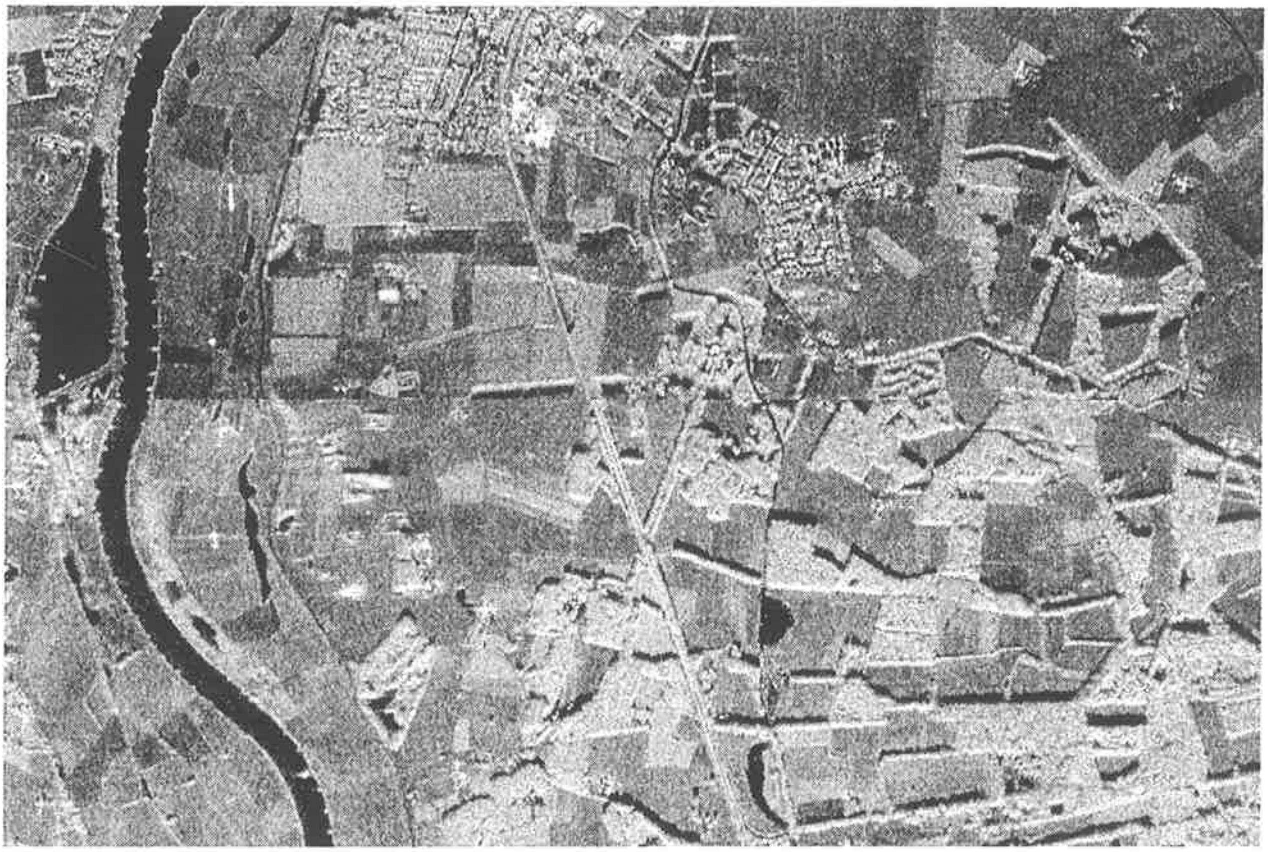
infrastructure, forest, agricultural areas etc. The terrain is flat up to a few meters. For this area the set of images shows resolutions ranging from 2 meters to 30 meters enabling a detailed comparison between the ground data and the extracted geographical information. Details of the data are given in Table 1.
All data were co-registered to the topographical maps 27 East and 27 West, with ground control points and using a stereographical projection and a Bessel ellipsoid as is usual for the Netherlands. The central point of the projection is located in the city of Amersfoort (RD co-ordinates (x, y) 155000, 463000 or 52.2° lat., 5.5° long.). The accuracy of the registration is determined by the geometrical accuracy of data and how accurately the ground control points can be determined with respect to the topographical map. This depends on the scale of the maps and on the resolution of the data. For the airborne data we used maps with a scale of 1:10,000, so that the data could be registered with an accuracy close to the dimension of the resolution cell. (i.e. 3 to 5 m). The satellite data could also be registered with accuracies within the dimensions of the resolution cell (i.e. 30 -10 m) using maps of 1:50,000 with exception of the KVR data which are accurately registered up to 10 m, while the resolution is 2 m. The is due to the lower geometrical accuracy of the KVR data.

**Table 1.** Remote sensing data for the Heerde test area.

| *sensor* | *platform* | *resolution (m)* | *type* | *date (d-m-y)* |
|---|---|---|---|---|
| TM | spaceborne | 30 | optical/nir-multispectral | 10-18-1993 |
| SPOT XS | spaceborne | 20 | optical- multispectral | 10-06-1992 |
| SPOT PAN | spaceborne | 10 | optical- panchromatic | 13-10-1992 |
| KVR1000 | spaceborne | 2 | optical- photographic | 19-05-1992 |
| ERS-1 | spaceborne | 25 (3 looks) | microwave- C-band/VV/23° | 06-08-1992 |
| JERS-1 | spaceborne | 25 (3 looks) | microwave- L-band/HH/35° | 20-09-1993 |
| CAESAR | airborne | 3 | optical- multispectral | 22-09-1994 |
| PHARS | airborne | 6 (8 looks) | microwave -C-band/VV/45-65° | 27-09-1994 |
| TIR-camera | airborne | 5 | thermal infrared scanner | 23-09-1994-<br>14-10-1994 |

CAESAR image (red band) of part (4.5 by 3 Km) of the Heerde test area



PHARS image of part (4.5 by 3 Km) of the Heerde test area

## 4. THE TERAS GROUND DATABASE

In order to evaluate the remote sensing data for cartographic purposes we have used primarily the so-called TERAS (Terrein analyse systeem) database [1] for the Heerde test site, containing detailed geographical data in vector format.
These geographical data are comparable to the information on a topographical map with scale 1:50,000.
At first instance a collection of features and attributes have been selected on basis of their relevance for military terrain inventory. These features and attributes are extracted from a DIGEST (Digital Geographical Information Exchange Standard) code list [2]. About 60 features are selected covering 6 categories, which are listed here:

1. Culture; which includes typically man-made object like buildings, roads etc. (code A).
2. Hydrography; for example rivers, canals, ditches, lakes etc. (code B)
3. Relief portrayal; spot elevation, contour lines (code C)
4. Land forms; for example barren ground, depression (code D)
5. Vegetation; for example trees, crop land (code E)
6. Demarcation; e. g. an administrative boundary (code F)

Not all features in the list are suitable for comparison with remote sensing data. For example administrative boundaries (category Demarcation) are difficult to monitor with the current remote sensing data or are not present in the Heerde test area. Some features, like different types of towers, were combined, since distinction would involve identification which is not possible with the current remote sensing data set. The category relief portrayal is not considered here, but will be investigated using the second test site near Freiburg. Taking the features suitable for comparison three categories (Culture, Hydrography and Land forms/ Vegetation) are left in a compressed list, which is shown below in Table 2.

**Table 2** Compressed list of features used in the comparison with remote sensing data.

| **Culture** | | **Hydrography** | | **Land forms/ Vegetation** | |
|---|---|---|---|---|---|
| Code | name | code | name | code | name |
| AQ040 | bridge | BI030 | lock/weir | DA020 | barren ground |
| AQ065 | culvert | BB140 | jetty | EA010 | cropland |
| AQ135 | stopping area | BH020 | canal | EB020 | heath |
| AL240 | tower | BI020 | dam | EA020 | hedge row |

| | |
|---|---|
| AL015 | building/complex |
| AT040 | pylon |
| AL070 | fence |
| AN010 | railroad |
| AP030 | road |
| AT030 | high tension line |
| AD030 | substation |
| AL020 | build-up area |

| | |
|---|---|
| BH080 | lake/ponds |
| BH090 | inundation |

| | |
|---|---|
| EA040 | orchard |
| EC030 | trees |

## 5. COMPARISON REMOTE SENSING DATA AND GROUND DATABASE.

We present here the comparison between vector data available in the TERAS data-set and remote sensing data collected for this study. The purpose of this comparison is to evaluate how accurately geographical information can be extracted from remote sensing sensors assuming that the TERAS data-set can be used as a complete reference data-set. In this way we try to determine the potential of remote sensing data for geographical information extraction.

In the comparison we have used the remote sensing images of the Heerde test area. For the satellite images we used TM, SPOT-PAN and KVR. The SPOT-XS image has been omitted in the comparison since it is expected that the results will average the results of PAN and TM. Also the ERS and JERS images are not considered here since the results are expected to be marginal compared to the other sensors. Only extracted point targets from these images have been compared with point features in the TERAS data-base. These results are shown and discussed in section 5.2. For the airborne images we used the CAESAR data, PHARS data and TIR data.

By comparing the various remote sensing images with the TERAS data-set (if needed also with the digitised topographical map) we have tried to determine for every feature how much of a feature was seen (i.e. *detected*) in the image. To do this different methods had to be used. For point data it is possible to count the number of points which are clearly related to objects seen in remote sensing images. The number of points which can be evaluated varies a lot for the different features. Usually the whole "Heerde" test area as imaged by PHARS and CAESAR has been taken for evaluation. In some cases the number of points is very large and a smaller area has been taken. In case of line or polygon objects also the length and area plays a role. A result is then obtained by inspection, for example by estimating the total detected length or area.

### 5.1 Results of the comparison

The results of the comparison are summarised in Table 3 for the six sensors mentioned above. The results are shown for the three classes: Culture, Hydrography and Land forms/ Vegetation. We discuss here the results for the three classes separately.

*Culture*

Some features like 'fences', 'towers' and high tension lines are generally too small to be detected by the sensors. For the detection of these features resolutions of less than 1 meter are required which are not available in the data-set. The low success rate of detection of towers is explained by the fact that towers are small when they are observed in vertical direction. For microwave sensors the viewing or look direction is not vertical (slant range geometry). The detection of towers is hindered in this case since the targets are confused with other targets in build-up areas where most of the towers are located.
The resolution of the TM sensors (30 m) causes this sensor to be less effective for detecting features in the category 'culture'. For SPOT-PAN the resolution of 10 meter makes this sensor 'intermediate' successful. Because KVR and CAESAR have relatively high resolutions (2-3 meter) most of the features are detected. Despite the somewhat lower resolution of CAESAR (3 m) compared to KVR (2 m) the first has a slightly higher success rate than the second because of the spectral information. Due to this information man-made objects and vegetation are easier to discriminate. The results for the TIR data are very sensitive to the emission and therefore to the temperature of the objects. The TIR data used here have been recorded during quite optimal conditions (late morning, clear sky). Man-made objects like bridges, roads and especially buildings are detected quite successfully, since they have been heated by solar radiation.
For the PHARS sensor the smaller objects like culverts and the smaller roads are difficult to detect because of the relatively low resolution (6 m) combined with the speckle.

*Hydrography*

The dimension of lakes and canals can vary substantially. For example the feature 'lakes' in the TERAS data-base contains many ponds sometimes overgrown by trees and the feature 'canals' contains many small ditches. This causes the detection rate to be quite low for the lower resolution sensors (TM and SPOT-PAN) despite the fact that these features are generally easy to detect.

The feature 'inundation' (IJssel Uiterwaarden) is difficult to observe directly since its main property is small scale relief over a large area. However the land use is different for the inundation compared to the surroundings so that observation of the land use makes detection indirectly possible. It appears that high resolution (< 5 meter) is advantageous for this purpose. The discrimination between water and vegetation is clearly more difficult for PAN recordings (SPOT, KVR) compared to multi-spectral recordings (CAESAR).
For the PHARS sensor the detection of canals is hindered by confusion with roads.
Despite the relatively high resolution of the TIR sensor (5 meter) the detection rate is substantially lower than that for the other high resolution systems (KVR, CAESAR) due to the fact that the contrast between water and the surroundings is not very high, especially when the water is surrounded by vegetation. However it should be noted that under certain circumstances, e.g. relatively warm water on a cold night water can be a dominant feature in the image.

*Land forms/ Vegetation*
In this case resolution is a less crucial parameter, since most objects are extended. For detection other information is important. Especially multi-spectral information plays a dominant role. This is due to the fact that vegetation reflects most of the light in the near-infrared compared to e.g. man-made objects.
By observing in the near-infrared vegetation differences also become apparent.
It is therefore that the TM sensor has an even higher detection rate compared to the SPOT-PAN sensor despite the difference in resolution. The same is true for the CAESAR compared to the KVR sensor.
The detection rate of the PHARS sensors is lower on average compared to the multi-spectral optical sensors. Like in the optical, also in the microwave wavelength region vegetation differences are more easily observed when additional information is available, for example from multi-wavelength systems or polarimetric systems. The single channel PHARS sensor therefore shows a relatively low detection rate.
The TIR sensor is not ideal to discriminate between different types of vegetation, since vegetation attempts to suppress temperature differences by controlling the evaporation of plant moisture. The detection rate is consequently relatively low.

**Table 3.** Summary of the ability to detect features for the different sensors

| | Name | TM | PAN | KVR | CAESAR | PHARS | TIR |
|---|---|---|---|---|---|---|---|
| **Results for category culture.** | | | | | | | |
| AQ040 | bridge | 10% | 50% | 80% | > 90% | 50% | 90% |
| AQ065 | culvert | < 10% | 20% | 70% | 80% | 20% | 20% |
| AQ135 | stopping area | 0% | 30% | 90% | 90% | 10% | 50% |
| AL240 | tower | < 10% | < 10% | 10% | 10% | < 10% | < 10% |
| AL015 | building/complex | 50% | 90% | 100% | > 90% | 80% | 100% |
| AT040 | pylon | < 10% | 10% | 70% | 90% | 90% | < 10% |
| AL070 | fence | 0% | 0% | < 10% | < 10% | 0% | 0% |
| AN010 | railroad | 70% | 90% | 100% | 100% | 100% | 80% |
| AP030 | road | 20% | 70% | > 90% | 100% | 50% | 70% |
| AT030 | high tension line | 0% | 0% | 0% | 0% | < 10% | 0% |
| AD030 | substation | < 10% | 60% | 90% | 90% | 90% | 90% |
| AL020 | build-up area | 60% | 80% | > 90% | 100% | > 90% | 100% |
| Culture | Average | 21% | 43% | 67% | 71% | 50% | 52% |
| **Results for category hydrography** | | | | | | | |
| BI030 | lock/weir | 0% | 0% | 30% | 40% | 40% | 40% |
| BB140 | jetty | < 10% | 40% | 90% | > 90% | > 90% | 50% |
| BH020 | canal | 30% | 20% | 60% | 80% | 30% | 50% |
| BI020 | dam | 20% | 40% | 50% | 40% | 40% | 30% |
| BH080 | lake/ponds | 30% | 30% | 60% | 80% | 80% | 50% |
| BH090 | inundation | 0% | 30% | 50% | 50% | 30% | 50% |
| Hydrography | Average | 15% | 27% | 57% | 63% | 52% | 45% |

**Results for category land forms/vegetation**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| DA020 | barren ground | 90% | 70% | 70% | 100% | 20% | 20% |
| EA010 | cropland | 60% | 60% | 70% | 90% | 80% | 70% |
| EB020 | heath | 70% | 80% | 80% | 80% | 50% | 40% |
| EA020 | hedge row | 50% | 70% | 80% | 90% | 80% | 90% |
| EA040 | orchard | 70% | 10% | 50% | 50% | 20% | < 10% |
| EC030 | trees | 60% | 80% | 90% | 100% | 90% | 100% |
| Land forms/ vegetation | Average | 67% | 62% | 73% | 85% | 57% | 55% |

## 5.2 Other comparisons with remote sensing data

*Roads*

By displaying the remote sensing images on screen and digitising the detected roads (AP030) manually a database was created containing vector data for the different remote sensing sensors for the Heerde test area. The total length of the roads can be calculated and compared with the total length of the roads in the TERAS database. In this way a more quantitative comparison can be obtained compared with the inspection method discussed above. We show the total length (in meter) and some statistics in Table 4.
Note that for PHARS two entries are available in Table 4. For PHARS I only the more obvious cases (dark lines) are extracted as roads. For PHARS II less restrictions are made and most of the dark lines are extracted as roads. Since roads (AP030) and canals (BH020) are easily confused in microwave images the result will be overestimated.

*Point features*

Microwave images are suitable for automatic point target extraction. Point targets can give increased backscatter which can easily be discriminated from the background with statistical means. The extracted points can be compared automatically with point features in the TERAS data-base, so that a quantitative comparison is possible. In this way ERS and JERS data, having improperly low resolutions for cartographic applications, may be used for the detection of point features. The comparison has been made for three ERS and one JERS images (see Table 5) and for the complete area covered by topographical maps 27 East and 27 West. A point was extracted from the images when the backscatter was 4.3 dB above the background giving more than 99% confidence that the point is not due to speckle.

About 3500 points representing mostly buildings and towers are selected from the TERAS database. A point feature in the TERAS data-set selection was said to be detected when it coincided within 50 m with a point extracted from the RS image. The result is that about 20% of the point features in the TERAS data-base are 'seen' by ERS and JERS (see Table). Another question is then how many of the 'detected' points are the same for all four cases, since the data differ not only in time but also in azimuth angle (different for descending and ascending passes) and in sensor (ERS/JERS). It appears that for cases 1 and 2 (difference in azimuth angle and time) 40% is the same, while for cases 2 and 3 70% is the same (difference in time only) and for cases 3 and 4 30% is the same (difference in sensor and time). The low value for cases 1 and 2 can be explained by the fact that the backscatter from point targets is quite dependent on the azimuth angle.

**Table 4.** Statistical data for AP030 (roads).

| *database* | *no. of elem.* | *total length (m)* | *mean length (m)* | *s.d. length (m)* |
|---|---|---|---|---|
| TERAS | 1646 | 433695 | 263 | 242 |
| TM | 1 | 107505 | - | - |
| PAN | 169 | 311750 | 1845 | 1621 |
| KVR | 2536 | 453285 | 178 | 201 |
| CAESAR | 807 | 619553 | 768 | 1256 |
| PHARS I | 64 | 147523 | 2305 | 2876 |
| PHARS II | 311 | 417945 | 1344 | 1638 |
| TOP50 | 702 | 557823 | 774 | 1337 |

**Table 5.** Comparison results for the ERS/JERS and TERAS point data-set

| *Case* | *Data* | *Date* | *Pass* | *Result* |
|---|---|---|---|---|
| 1 | ERS 1 | 23 06 92 | ascending | 22% |
| 2 | ERS 2 | 02 07 92 | descending | 20% |
| 3 | ERS 3 | 23 06 92 | descending | 24% |
| 4 | JERS | 20 09 93 | descending | 20% |

## 6. CONCLUSIONS

It is difficult to draw general conclusions for the whole set of features, since the characteristics of the features are quite diverse. In principle every feature needs to be considered on its own. By grouping features into classes some general conclusions can be drawn, since many of the 'culture' features are point targets, while the 'land forms/ vegetation' features are often polygons.
In general we can say that most of the features of the DIGEST list in Table 2 can be detected and recognised when the resolution and the wavelength is appropriately chosen. Man-made features like building or roads can be detected and often recognised quite adequately when the resolution is appropriate, i.e. less than 5 meter. The recognition of towers is difficult when the viewing direction is vertical. Direct detection of fences and power transmission lines is difficult due to their small dimensions. For resolutions less than 1 meter most features can be recognised. For extended features like crop land or forest multi-spectral or polarimetric information is more important than the resolution. Some features like inundation (BH090) and underground water (BH115) are difficult to observe directly with remote sensing sensors. Sometimes information can be obtained indirectly by observing other features which are related (i.e. context information; for example, green vegetation in case of available underground water).

Optical sensors make use of daylight and are weather dependent. For optical sensors high resolution images can be obtained, which facilitates the recognition of objects. Radiometric resolution and spectral information are also quite important to discriminate objects, especially between made-made objects and vegetation. Near-infrared information is very useful to discriminate different types of vegetation.

TIR sensors are very suitable to detect and to recognise man-made objects, like buildings, roads etc., when the circumstances are good (i.e. clear and sunny weather). However the circumstances are very crucial for TIR sensors. During a cloudy, misty or rainy day the contrast vanishes and objects (also man-made objects) are hardly visible in the image. For the discrimination of vegetation types TIR sensors are less suitable.

The main advantage of microwave sensors is that they are independent of most circumstances since it is an active sensor which can be used in principle during all weather conditions and at night. Microwave sensors can be appropriate for detecting objects due to specular reflections which give high returns in the image even when the resolution cell is significantly larger than the object (e.g. high tension pylons in ERS images). The result is a point feature which does not allow recognition. In general the ability of microwave sensors to recognise objects is rather low. Even when more resolution cells are covering the object recognition is difficult since then usually only a collection of points is seen. The contour of the object which is the main feature for recognition in the optical and TIR is in microwave image suppressed due the appearance of specular reflections and speckle. The low resolution of present-day spaceborne sensors is clearly disadvantageous for obtaining geographical information.

A quite important concept for detection and recognition is 'context information'. The context can provide information about a feature even when the feature cannot be observed directly. Since in many cases features show up as small objects in the image only a few pixels provide information limiting the recognition. However other independent information available for the interpreter, for example background information about location and the surroundings can provide the essential information so that recognition or even identification becomes possible. This so-called 'context information' will always play an important role in using remote sensing images.

## 7. ACKNOWLEDGEMENTS

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## 8. REFERENCES

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PAPER No: 3

DISCUSSOR'S NAME: G. S. Brown

COMMENT/QUESTION:

What is your experience using radar data over foliage covered terrain?

AUTHOR/PRESENTER'S REPLY:

Foliage coverage from forests and tree-lines can be detected by radar, but the polarimetric radar performs much better in detection and classification of trees and tree types through their foliage than the single channel, fixed polarization. For the detection of structures under the foliage, penetration is required. Foliage penetration is only possible with low frequency radars, which are usually limited in their resolution.