IMPROVEMENT OF CLASSIFICATION RESULTS FROM A SATELLITE IMAGE USING CONTEXT INFORMATION FROM A TOPOGRAPHIC MAP

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RESUME

The study described in this article examined the possibilities of using Landsat Thematic Mapper images for updating land-use information on topographic maps. Information obtained from satellite images can be kept up to date and a large number of classifications can be distinguished. However, the information still leaves much to be desired, with a reliability of no more than 40 - 90 %. Using the topographic information from 1980 as a point-by-point reference the results of a satellite image classification of 1986 could be significantly identified for well over 95 %. The method used also led to the identification of a large number of additional classes and provided quantitative insight into the dynamics of landscape change. The results presented in this article provide a forecast of landscape dynamics based on the map and satellite information. The next step will be verification of the results on the basis of aerial photographs as soon as these are available. In view of the reliability attained, it can be expected that wherever topographic maps permit extraction of landuse information in a similar way, remote sensing information will find useful applications in e.g physical planning.

1. INTRODUCTION

Generally speaking, satellite imagery and topographic maps are the two most accessible and complete sources of geographic information. Both sources have practical advantages and disadvantages:

- Topographic maps are the most accurate sources of geographic information. But the making of these maps is extremely labour intensive. In The Netherlands such maps are not available until three to five years after the aerial photographs have been taken and they are only updated once every five or ten years. Geometric accuracy is thus obtained at the expense of topicality. Since they represent the most accurate and complete source, the maps are used for many purposes. As geographic (land-use) classes are defined and distinguished differently by different disciplines, the classes on the topographic map are often considered as rigid (ref. 2 and 4).
- Satellite sensors have been providing new images of the situation on the surface of the Earth from all over the world for the last fifteen years. Study of all the Landsat images made of The Netherlands between January 1st 1975 and December 31st 1986 (ref. 2) showed that a cloud-free image of the whole country can be obtained on average twice a year while in the case of smaller areas measuring 50 x 50 km this is the case five times per year. The accuracy of the information that can be obtained from these images, however, often fails to measure up to the requirements of the Western World (ref. 2, 3 and 4).

In this study the thematic surface information from a topographic map was digitized. In such a form the topographic information can be used as a point by point frame of reference for improving a satellite image classification.

2. AIMS

The aims of the study were:
- the development of a method for improving the reliability of land-use information obtained from satellite imagery by applying existing information from a topographic map.
- the determination of the flexibility of the method for distinguishing different types of land-use.

3. MATERIAL

Topographic information can be combined with satellite images either photographically or digitally. The digital approach was chosen for the purposes of this study in order to attain a maximum level of geometric accuracy, to obtain the greatest possible measure of flexibility in combining the data and because of plans to automate the process in a subsequent stage of the study.
An Optronics 4040 scanner of Intergraph Europe Inc. was used to digitize the topographic information. All further processes were carried out on the NLR's RESEDA image processing system which is based on DIPIX system.
As test area the the 20 x 25 km region covered by 51 East topographic map sheet of Eindhoven was chosen. This map was published in 1985 on the basis of aerial photos made in 1980. The classification of satellite images was done on band 3,4 and 5 of Thematic Mapper image 198/24 from August 3, 1986. The reasons underlying the choice of this area were that the classification of the area had already been carried out - as described in Ref. 4 - and he results of the classification were very satisfactory. Further a great deal of field data had been collected which rendered possible further refinement and verification of the results with the new technique.

4. METHOD

The printing technique used for producing a Dutch topographic map involves the use of six "master" end films. These end films are produced from twenty partial films of linear and surface thematic elements. These partial films can be made available separately by the national topographic service.
In the study the surface information from the topographic map was used. The following classes from map sheet 51 East were processed:

1. built-up area
2. tarred roads
3. highways and main roads
4. water
5. heathland
6. forest and woodland
7. grassland

Dirt roads, minor roads in built up areas, agricultural land and all the remaining classifications such as railways, railway yards, construction sites, etc. have no specific classification on the topographic map and are left "blank". Sand dunes (yellow colouration) occur rarely in the region covered by map sheet 51 East and were thus not digitized.

4.1 Digitizing and integrating topographic information

During digitizing the films were mounted onto a fixed background so that they could be combined pixel by pixel, without further corrections. The films were scanned separately and subsequently each of the seven themes was accorded a unique code and integrated in one theme file.
From the blank rest class, agricultural land and construction sites can be obtained reasonably well from a satellite image by means of classification. The "blank" roads cannot be determined from a satellite image because they are too narrow. It is thus important to obtain these classes of roads from the topographic data. This was accomplished by using filter techniques. Subsequently the class was added to the other seven classes as a separate class 8. The technique used, is described in the report on this phase (ref. 6).

4.2 The Thematic Mapper image classification

The classification result of the Thematic Mapper image (as described in ref. 4) was taken as point of departure for the 1986 and the "view" from space. The classes distinguished were as follows:

1. Maize land
2. Grassland
3. Cabbage land
4. Water
5. Man-made infrastructure (houses, built-up areas, roads in so far as detectable with 30 m pixels.
6. Deciduous forest
7. Pine forest
8. Heathland
9. Bare land including fallow agricultural land and construction and industrial sites.

Of the total number of pixels 0.3 % were not classified.
The reliability of the classification result was tested against actual land-use over an area of 1,650 hectares. Land-use in the sample of 1,650 hectares was determined by field work. Table 1 - taken from ref 4 - shows the resulting confusion matrix for the principal classes.

The accuracy with which this geometric correction was carried out is indicated in table 2. Use of the spectral signatures still available of the nine land-use classes permitted the classification results to be reproduced with corresponding dimensions.

Table 1: Confusion matrix of the classification result between the four main classes on the basis of field data (in hectares and percentages).

Ground truth	Classification results				
	Grassland	Maize	built up area	Pine forest	Deciduous forest
Grassland 774 ha	696,9 ha 88,9 %	21,3 ha 3,1 %	23,5 ha 3,4 %	13,5 ha 1,9 %	13,3 ha 1,9 %
Maize fields 651 ha	49,3 ha 8,6 %	596,8 ha 87,1 %	15,1 ha 2,7 %	7,1 ha 1,2 %	2,5 ha 0,43 %
Pine forest 81,1 ha	-	-	-	67,6 ha 80,8 %	13,0 ha 19,2 %
Deciduous forest 144,4 ha	-	-	-	-	143,7 ha 99,5 %

Table 1 shows that the reliability of the result of most of the classes varies between 80 and 90 %. Although this is not bad for a classification result, it is still not good enough for many fields of practical application - physical planning, for instance - since structural changes of in land-use amount to maximally 1-2 % annually. The most important aim of this study is to verify the extent to which the accuracy can be improved in order to permit accurate assassment of changes.
The information of the land-use classification measured 800 x 1000 image points, each covering 25 x 25 m. This information could not be directly combined with the 1000 x 1253 image points (of 20 x 20 m) of the file containing the topographic information. In order to achieve a matching, a resampling was carried out of the raw image data from bands 3, 4 and 5 of the Thematic Mapper image. The accuracy with which this geometric correction was carried out is indicated in table 2. Use of the spectral signatures still available of the nine land-use classes permitted the classification results to be reproduced with corresponding dimensions.

Table 2: Geometric accuracy of the combination of satellite data with topographic information

File	Number of reference points used	Root mean square error	Maximum deviation	Minimum deviation
Reference file: Topographic theme file				
TM band 3, 4, 5	17	5 m	20 m	2 m

4.3 The combination of topographic with satellite information

The following method was used for bringing the topograhic map up to date and to improve the satellite image classification:
A unique code was assigned to each of the eight classes from the topographic map and of the nine classes from the classification of the satellite image. By adding up the files, 89 combinations were obtained. The codes are set out in table 3 in the top left-hand corner of each square. The surface area (in hectares) occupied by each of the 89 classes is indicated in table 3 in the bottom right hand corner of each square.

Each of the 89 combinations in table 3 has a certain meaning which may or may not be significant. The significance of the different code combinations can be determined by knowledge of changes occurring in the area in question and by acquaintance with the way in which a topographical map and a satellite image classification are made.
The most important differences between classes on a topographic map and from a classification from a satellite image occur with roads, forests and man-made constructions:

1) Roads:
   Both tarred and dirt roads on the topographic map and in the digitized version are shown with an exaggerated width of 0.4 or 0.6 mm. On a 1:50,000 scale map this corresponds to 20 and 30 m. Most roads - apart from highways - are, in fact between 4 and 8 m wide. The actual area so designated on the map is therefore three to five times smaller than in reality. The area occupied by highways is reproduced reasonably well. Roads narrower than 10-12 m cannot be detected on Thematic Mapper imagery (ref. 5). Only arterial roads and highways can be expected to be expressed to a certain extent in the classification result, and not, in any case, as a separate class but included under the class "man-made infrastructure".

Table 3: Combination table of topographic and satellite information.

THEM 1986 TOP1 1980 CODE	NOT CLASSI-FIED 0 ha	MAIZE LAND 9 ha	GRASS LAND 18 ha	WATER 27 ha	CABBAGE LAND 36 ha	DECIDUOUS LAND 45 ha	PINE FOREST 54 ha	HEATH LAND 63 ha	BUILT UP AREA 72 ha	BARE LAND 81 ha	TOTAL SURFACE PER CLASS
Agriculture, Building grounds, Remaining area 0	0 42	9 3685	18 2852	27 33	36 95	45 1334	54 187	63 200	72 1998	81 282	10708*
Built up area and Houses 1	1 20	10 25	19 184	28 33	37 -	46 216	55 71	64 130	73 3401	82 41	4121
Tarred roads 2	2 8	11 136	20 664	29 16	38 -	47 570	56 141	65 38	74 1190	83 16	2779
Water 3	3 6	12 140	21 85	30 248	39 -	48 126	57 69	66 117	75 101	84 33	925
Heath land 4	4 -	13 -	22 57	31 44	40 -	49 126	58 122	67 997	76 117	85 16	1479
Motor ways and main roads 5	5 3	14 8	23 40	32 16	41 -	50 40	59 34	68 264	77 453	86 -	858
Forest 6	6 8	15 146	24 475	33 107	42 -	51 2850	60 3895	69 298	78 1190	87 44	9013
Grassland 7	7 33	16 3619	25 9857	34 39	43 82	52 1556	61 53	70 200	79 1140	88 216	16795
Dirt roads and small roads in town 8	8 10	17 180	26 454	35 44	44 -	53 810	62 428	71 158	80 1330	89 28	3442
Total surface per class	130	7939	14668	580	177	7628	5000	2402	10920	676	50120*

* of which 120 ha outside map area

2) Forest and woodland:
On a topographic map a wooded area is indicated as a surface element if the width at the base of the trunks is more than 3 m. Narrower rows of trees and other linear plantations are reproduced in linear and punctile symbols. A Thematic Mapper classification reproduces all deciduous and pine forest patterns with a crown width of over 15 m.
On a satellite image no distinction can be made between a row of trees in the fields and a lane lined with trees.

3) Man-made constructions:
In general, in a process of classification no clear distinction can be made between roads, buildings and - for instance - parking lots. All of these are included under the class "bare, highly reflecting surfaces not covered by vegetation". A topographical map reproduces roads, free-standing houses and housing blocks within a built-up area separately. However, farm-yards, car parking areas and - for instance - railway yards are often not indicated as separate elements (on a 1:50,000 scale map).

4.4 Verification

An important aspect of the interpretation of the codes from table 3 is the elimination of spectral confusion within the classification result by using contextual data derived from the topographic map. The statements made in this paper are based only on general knowledge of the area and of topographical maps and classification processes. For that reason they must be considered as "logical likelihoods" only. At the time of writing, the aerial photographs of the region needed for verification of the result were not available yet. And therefore the results reported should, for the time being, be regarded as a hypothesis to be tested at a later stage against the aerial photographs. The definitive report (ref. 6) will describe the results of the verification process.

5. RESULTS

5.1 Reliability of the basic data

One of the aims of the present study is to determine the extent to which the reliability of classification of a satellite image can be improved. This means that first and foremost the reliability of the basic data should be known.

1) It can be assumed that on the topographic map, derived from 1:18,000 scale aerial photographs and for which minutely detailed field information has been collected, the area of each class indicated is correctly represented within the bounds of its definition. However, problems do arise when it is a question of determining the area covered by roads which are represented as too wide, in the case of rows of trees not shown as surface elements and when the extra "unclassified" terrain has to be divided up as to land-use.
   Over-estimation by a factor of 3 to 5 of the area occupied by roads means that of the 7,079 hectares indicated for roads in table 3, only about 2,000 hectares are in fact covered by roads. That means, that the average accuracy with which the area occupied by other classes is represented is reduced by this effect alone to 90 %.
2) The reliability of the Thematic Mapper classification result (see table 1) was estimated at 80-90 % on the basis of field samples. As the topographic information has been made available for the total 50,000 hectare area, statements can be made about a number of other aspects, e.g. the reliability of classes barely sampled - if at all - such as heathland, water, urban development. Further an integral overview is obtained rather than one based on samples. Of course, the 1980 situation does not necessarily need to bear a direct relationship with that obtained in 1986.
   The reliability of classes obtained from the satellite image was determined by taking all the codes in table 3 showing a plausible temporal relationship. A number of examples can clarify this approach:
   - Code 73 indicates that 3,401 hectares were occupied not only by "town" in 1980 but also by "man-made constructions" in 1986, and there is little reason to dispute the correctness of this in view of the stable character of building construction at the time.
   - Because of the limitations of a classification, code 77 - indicating "highway or arterial road" in 1980 and "man-made constructions" in 1986 - is likewise subject to little doubt.
   - However, classes which show a great deal of spectral overlap and do not normally flow into one another, such as "forest" to "water" (code 33, 107 hectares) and "water" to "pine forest" (code 57, 69 hectares) are very likely due to to mis-classifications (i.e. spectral confusion).

In table 4 an overview of the likely reliability of the classification classes is given as a result of the analysis of the plausible relationships between map and classification. The reliability of the classes shows considerable differences, from 41.5 % to 100 %, with the highest percentages found in those classes that were given special emphasis because of the aim of the project: obtaining distinctions within the agricultural area. The average accuracy of 89.9 % is according well with the results shown in table 1.

Table 4: Reliability of classification based on data of the topographic map

CLASSES	RELIABILITY in %	RELIABILITY in ha
1. Not classified	0	0 of 130
2. Maize land	97,1	7707 of 7939
3. Grassland	92,8	13615 of 14668
4. Water	42,7	248 of 580
5. Cabbage land	100	177 of 177
6. Deciduous forest	100	7628 of 7628
7. Pine forest	98,6	4931 of 5000
8. Heath land	41,5	997 of 2402
9. Built-up area/roads	84,6	9240 of 10920
10. Bare land	73,7	498 of 676
Total reliability	89,9	45041 of 50120

NB: Table 5, where all the results are indicated separately, should be consulted in order to see how the areas indicated in table 4 were arrived at.

5.1 Maximum obtainable reliability and diversification of the classification result

The aims of this study were to clarify the extent to which reliability and diversification of land-use information can be obtained by using the possibilites offered by the two sources of information.
Table 5a and 5b are the result of analysis of the 89 codes indicated in table 3.

Table 5a,b: Real extend of land-use classes in 1986 according to the classification of a Thematic Mapper image, with maximum use made of topographic information.

Table 5a: Real extent of original classes

DESCRIPTION	TOTAL AREA	NOT CLAS-SI-FIED	MAIZE LAND	GRASS LAND	WATER	CABBAGE LAND	DECI-DUOUS FOREST	PINE FOREST	HEATH LAND	BUILT-UP-AREA	BARE LAND	TOTAL AREA WITHOUT VISUAL CORRECTION	TOTAL AREA WITH VISUAL CORRECTION
Not classified	130	102								20		20	
Maize land	7939	(66)[3]	(7641) 7707									7707	
Grassland	14668	72		13615								13615	
Water	580	148			248			107	44			399	
Cabbage land	177	-				177						177	
Deciduous forest	7628	-			126*		7628*					7628	
Pine forest	5000	-			69			4931				5000	
Heath land	2402	151			117			298	997	130	400	1942	
Built-up area	10920	33 (650)[2] (90)[4]								6467 (1100)[2] (90)[4]	(650)[2]	6467	(8307)
Bare land	676	32								41	498	539	
	50120	538 (1344)	7707 (7641)	13615	560	177	7628	5336	1041	6658 (7848)	898 (1548)	43494 86,8%	(45334) 90.4%

* Deciduous forest over water falls in both classes

Table 5a is a "confusion matrix" (indicating the extent of spectral confusion between the classes at classification) in which the time factor also plays an important part. The most important information that can be derived from the image classification and from the topographic map has been indicated in this table.
The difference between this and a real confusion matrix is that use of the topographic information for the whole file now permits the confusion to be identified to such an extent that usually corrections can be made. It is not possible, within the scope of this article, to go into the reasons underlying the according of each individual code to the uncontaminated classes specified. A number of specific areas are placed between brackets. This means that they have been identified by visual interpretation of one of the derived thematic maps.
E.g. by visual inspection it became apparent that the passage from forest to urban development (code 78, 1,190 hectares) affected only approximately 90 hectares which had gone from being forest to actual urban development. The greater part (approximately 1,100 hectares) consisted of recently felled forest. Apparently the spectral signature of disturbed humus and sand has many characteristics in common with that of the average appearance of gardens, houses and roads. In this case, it would be better to regard the code as "tree-felling area", which means that 90 hectares have been incorrectly designated.

Table 5b: Real extent of new classes

	TARRED ROADS OUTSIDE TOWNS	MAIN ROADS INSIDE TOWN	MAIN ROADS AND HIGH WAYS	DIRT ROADS OUTSIDE TOWN	MINOR ROADS INSIDE TOWN	MARSH LAND	FELLED FOREST	HEATH LAND INVADED BY GRASS	HEATH LAND INVADED BY DECIDU-OUS FOREST	HEATH LAND INVADED BY PINE FOREST	DAMAGED HEATH LAND	RAIL ROADS	EMPLIED LAKE	TOTAL ACREAGES WITHOUT VISUAL CORRECTIONS	WITH VISUAL CORRECTIONS
Unclassified	3			2										5	
Maize land	48		8	36		140								232	
Grassland	233		40	91		85	475	57						981	
Water	6		16	11										33	
Cabbage land														-	
Deciduous forest	199		40	162					126					527	
Pine forest	49		34	86						122				311	
Heath land	13		264	32										309	
Built-up area		415	453		465		(1100)[4]				117	(250)[2]		1450	(2800)
Bare land	6			6			44				16		33	95	
	557	415	861	426	465	225	519 (1619)	57	126	122	133	(250)	33	3943 7,8%	(5293) 10,6%

2) These classes (1988 ha in total) can only be separated visually.
3) These classes (146 ha in total) can only be separated visually.
4) These classes (1190 ha in total) can only be separated visually.

Table 5b gives the classes that have not been directly classified but can be deducted from the combination with the topographical map data.

- Tree-felling areas do not possess a characteristic spectral signature. Depending on the percentage of sand, humus, grass and new growth, areas designated as forest in 1980 are classified as grassland, urban development or fallow agricultural land.
- The extent to which heathland has been invaded by grass, the advance of deciduous and pine forest, and the acreage of heathland damaged by sod-cutting, by destruction and by construction works can be determined by the amount of heathland given in table 4 as grassland (code 22, 57 hectares), deciduous forest (code 49, 126 hectares), pine forest (code 67, 122 hectares) and urban construction or fallow agricultural land (code 76, 117 hectares and code 85, 16 hectares).
- Railways and railway yards cannot be distinguished as a specific combination of classes, but because of their visual form can be distinguished within code 72, 1,998 hectares.

Several classes have been mentioned twice in table 5a or 5b as they have a double significance. A double significance applies to all roads, water and construction works which cannot be detected from space because they are overgrown by trees and are thus functionally and road or water or construction and forest.

5.3 Another look at reliability

Taking into account all the corrections, the acreage originally incorrectly designated or about which no certainty as to its use could be obtained, is now considerably less than that reported in table 4, having been reduced from 5,079 hectares (or 10.1 % of the total area) to 538 hectares (or 1.2 %) if the visual corrections are calculated in, and to 1,344 hectares (or 2.7 %) if no account is taken of the visual corrections.
Table 6 gives a break-up of these overall percentages per class.

Table 6: Reliability of the classification results per class after correction with the aid of the topographic reference information

	TOTAL AREA	NOT DEFINED	DEFINED	
			PERCENTAGE	TOTAL AREA (ha)
Not classified	130	102	21,5 %	28
Maize land	7939	(66)	99,2 %	(7939) 7873
Grassland	14668	72	99,5 %	14596
Water	580	148	74,5 %	432
Cabbage land	177	-	100 %	177
Deciduous forest	7628	-	100 %	7628
Pine forest	5000	-	100 %	5000
Heath land	2402	151	93,7 %	2251
Built-up area	10920	33 (740)	93,7 %	(10887) 10147
Bare land	676	32	95,3 %	644
Total with visual corrections	50120	538	98,8 %	49554
Total without visual corrections		(1344)	(97,3 %)	(48748)

5.4 The end products

All changes indicated in table 5 have been documented on Optronics film. The classes have been documented per theme. The following products have been derived from table 3:

1) Changes in agricultural land-use
2) Changes relating to built-up areas/man-made infrastructure.
3) Changes related to forest acreage.
4) Changes related to heathland.
5) Changes related to surface water.
6) An up-to-date topographic map of the 1986 situation.
7) A Thematic Mapper classification in which the classification errors have been corrected in so far as is possible.

6. EVALUATION AND CONCLUSIONS

6.1 Integration of topographic information with satellite imagery

In the Netherlands depending on the region, a new version of a topographic map is brought out every 5 to 10 years. At the time of publication, the information it contains, dates from 3 to 5 years previously.
Map users therefore always have to be alert for post-production changes. These can be determined by field work, by obtaining and interpreting aerial photographs or via a combination of the two, but such methods are labour intensive and expensive. In this study, the use of satellite images has been examined for its usefulness as an alternative source of information renewable at least twice annually for every region of The Netherlands.
It has become clear that a combination of satellite data and existing information permits detecting and quantifying changes in the landscape. This study looked at the possibilities for completely updating information contained in one map sheet. The method delivers information on changes over a period of time for practically every image point. The satellite image itself was not used, but rather information previously obtained via any information extraction procedure, e.g. a (maximum likelihood) classification procedure. Classifications provide information with a reliability of 40-90 %, depending on the class. This is insufficient for most applications in The Netherlands and the Western World. The combination of the classification result with the topographic information makes it possible to improve the reliability of the information obtained to well over 95 % and also to distinguish various additional classes. The study of possibilities on the combined use of topographic and satellite information, in so far as described in this article, concentrated exclusively on processing via what are known as "look-up table transformations". These are remarkably simple and rapidly performed manipulations of the class codes, as given in table 3. Emphasis in look-up table processing is placed on knowledge of the trends in changes in the landscape and of the differences between the information provided by the topographic map and the classification result.

6.2 Accurate land-use information

The analysis of the result of a maximum likelihood classification as given above, illustrates that spectral information from satellite images cannot always provide an unequivocal version of the required functional classes. To achieve this, additional information is needed.
The approach adopted in this study has shown that the combination of a satellite classification (including all the spectral "confusions" as seen from a functional point of view) with topographic information as functional frame of reference can both explain and correct the majority of the "errors".

6.3 Possible improvements to the method

The following steps leading to further improvement are the subject of current investigations:

- Using information from the topographic map as a mask in order to extract from the satellite image information relevant to a functional class such as forest or heathland. This opens up the possibility of reclassifying such classes without the disturbing influences of spectral overlap with other land-use classes. It can be expected that in this way it will be possible to obtain much greater accuracy of classification and a further differentiation of land-use classes. This will enable to provide information not otherwise obtainable for a number of specialised disciplines.
- The procedures adopted with the Thematic Mapper at 20 m resolution can also be performed at a resolution of 10 m when SPOT panchromatic bands and SPOT bands (or Thematic mapper bands) are combined. This will produce resolution four times more detailed and will also, for example, lead to the production of an image much more acceptable to a human eye, accustomed to cartographic accuracy. However, the processing will take longer and will thus be more expensive.

6.5 Conditions for achieving a reliable result

It would be untrue to state that the method described can raise every classification result to an acceptable level. A number of conditions have to be met before a high level of reliability can be achieved:

- First of all, the required classes have to be available, either on the topographic map or have to be obtainable with reasonable accuracy from a satellite image. Any attempt made to determine the area covered by maize from a winter image, for example, is doomed to fail.
- Correction of the classification results requires adequate topographic information. The map chosen should not be very out of date, i.e. no more than 20 years old, but depending of the degree of structural change that has occurred.
- During the classification procedure, extra account should be taken of the required classes which are not available with sufficient accuracy in the context information.
- The two sources of information need to be correctly matched geometrically with one another.

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