CONTRAST ANALYSIS IN VERY HIGH-RESOLUTION IMAGERY FOR NEAR AND FAR NEIGHBOURHOODS

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ABSTRACT:

Contrast analysis has a tradition in remote sensing and usually includes a limited amount of neighbouring pixels using a predefined kernel size. An object based approach allows the evaluation of contrast on near as well as very large neighbourhoods within a context of thousands of neighbouring pixels. Due to the variety of pixels on very large neighbourhoods, artificial areas behave typical in their response to contrast analysis. This behaviour is used to map high contrasting areas and confront the results with topographic map information containing building footprints (resulting in less than 1% omission failures for build-up structures). In addition to associating this contrast mapping and building footprints, detection of artificial structures on agricultural parcels is also analysed.
Approximately 5% of the agricultural parcels contain sufficient contrast, mainly related to new build-up areas, with a commission failure (or false alarms) of 13%. The contrast analysis can prioritize agricultural parcels for potential update, allowing automatic analysis for the whole country at acceptable costs.

1. INTRODUCTION

Contrast analysis plays a fundamental role in remote sensing due to its contribution in detection of build-up areas and infrastructure, both in visual and in automatic image interpretations. It enhances spectral differences within a predetermined spatial neighbourhood and hence captures transitional boundaries or zones. Surface cover and different construction material over artificial areas show a variable response to passive spectral sensors. The overlap of their spectral mean values with other classes makes their distinction complex. In addition, shadow-induced contrast is not a unique property of build-up surfaces. The abrupt changes of local spectral response in spatial layout can be expressed in different contrast properties and used in the classification process.

Contrast can be assessed at different scales depending on the spatial resolution of the imagery and the selected window size (which is often either 3x3 or 5x5 kernel). Contrast calculations at different scales are useful for a variety of applications, including change (Walter, 2004) and anomaly detection, as well as the flagging of areas which may require topological map update. Traditional approaches, based on the co-occurrence matrix, calculate contrast by using relatively small kernel sizes (e.g. Pesaresi et al. 2008). It is useful to extend on these experiences by contrast analysis using very large neighbourhoods. This becomes possible in a single-pixel object approach which is less restricted to the maximum kernel size (de Kok and Taşdemir, 2011).

The aim of this study is to detect artificial areas within an agricultural environment. We have shown advantages of such contrast calculation in high spatial (5 m) resolution in de Kok and Taşdemir (2011). Particularly, in this study, we extend its use towards very-high (less than 1 m) spatial resolution imagery. Section 2 explains the object based approach for contrast analysis. Section 3 assesses artificial area extraction by confrontation with topographic map information (with an emphasis on negligible omission errors), and by specific detection inside an agricultural database (emphasizing commission errors). Section 4 concludes the paper.

2. AN ALTERNATIVE CONTRAST CALCULATION BASED ON SINGLE-PIXEL OBJECTS

Single-pixel objects and their contrast are calculated by considering each pixel as an object and using the contrast definition as applied in eCognition (version 8.64 by Trimble/Definiens 2010)

$$\Delta_k(v) = \frac{1}{w} \sum_{u \in N_v(d)} w_u (c_k(v) - c_k(u))$$

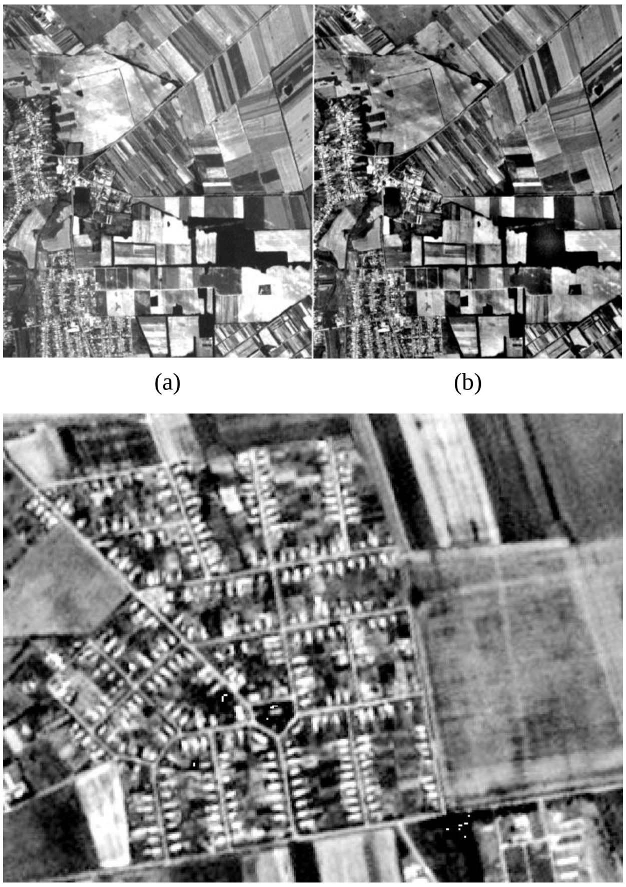
where u, v are object mean values, c_k is the mean intensity of the image layer k, and w is the image layer weight, defined as the sum of the weights of image object, $w = \sum_{u \in N_v(d)} w_u$, with

$$w_u = \begin{cases} b(v,u) & if\ d = 0 \\ \#P_u & otherwise \end{cases}$$

where $b(v,u)$ is the length of the common border between u and v, $\#P_u$ is the total number of pixels/voxels contained in P_u, and $N_v(d)$ is the set of neighbours to v at a distance d:

$$N_v(d) = \{ u \in V_i : \mathrm{d}(v, u) \leq d \}$$

A variable distance "d" is mainly responsible for reaching different results. The value expresses the distance up to which neighbours are taken into account, namely, it can be regarded as "search radius" (for example d=10 results in 10*10*π=314 neighbouring pixels). This object based approach allows very large extension of the neighbourhood (large d values), which makes it possible to include thousands of neighbouring pixels. In Figure 1b, for example, a distance d = 50 evaluates contrast using 7852 neighbouring pixels.



(a) (b)

(c)

Figure 1. Example contrast for d=50 using equation 1 on RapidEye imagery red band: (a) RapidEye red band, (b) Single-pixel object based contrast with d=50. The “glare” disappears over bright open fields, whereas build-up areas have more enhanced values. (c) An enlarged part of this contrast, to show enhancement of buildings in the village.

Contrast on large neighbourhood served well in the 5 meter spatial resolution of RapidEye (de Kok and Taşdemir, 2011). The response to contrast in 5 meter resolution apparently relates to the complete build-up structures within settlements (as can be seen in Figure 1c and also indicated by Pesaresi et al. 2008). Moving to the very high spatial resolution (for example 50 cm resolution of GeoEye), the contrast response is not directly related to the roof area but rather appears on the transitions from roof to wall or deviating details inside roofs. Therefore, the analysis only produces contrasting parts of the building and its direct surrounding, instead of complete roofs over built-up structures (Figure 2). Roof-covers are relatively low in contrast in GeoEye imagery (due to the construction material in the study area, mostly red ceramic tiles). Specific building material is not taken further into account in the contrast analysis. This low contrast of the roof itself compared to high contrast on transition zones between roof and wall is partly due to the range of the panchromatic band that includes the infrared. The contrast in the infrared band is more related to vegetation whereas the red band has higher reflection and contrast over artificial areas. This would indicate that this type of contrast would be affected by larger off-nadir angles showing a larger part of the building faces versus roof area in the imagery for sub-1 meter resolution. This fact is not elaborated but might need additional stereo imagery in the sub- 1 meter resolution.

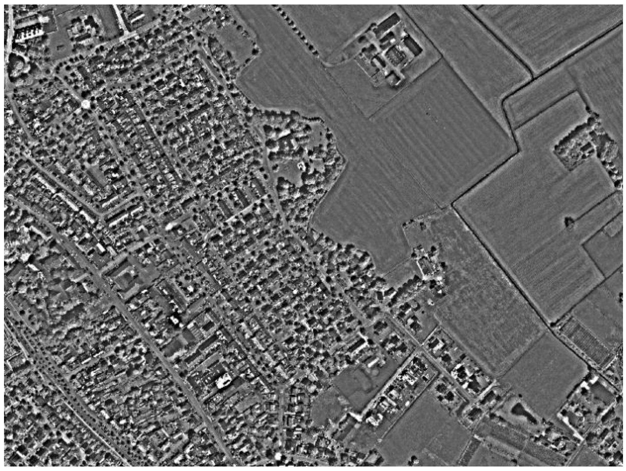
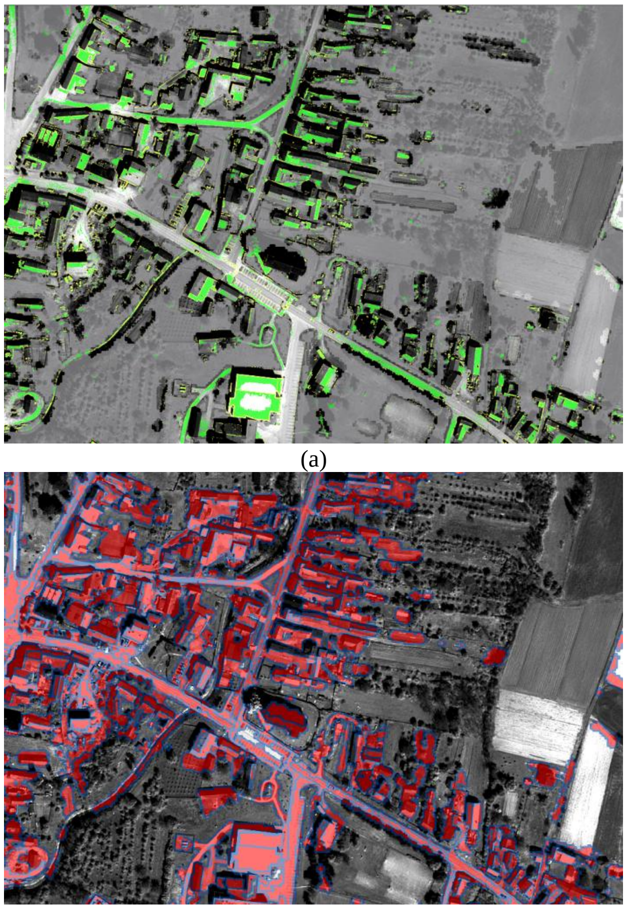


Figure 2. Contrast image on single-pixel-object based contrast for very-high resolution (0.5m) imagery, with d = *20***.** Contrary to 5 m resolution, only parts of buildings are highlighted in the 0.5 m resolution.



(a)

(b)

Figure 3. An object segmentation based on contrast for GeoEye: (a) Contrasting single pixel seed-objects for d=20 (green) and d=1 (yellow) (using an image with 50 cm resolution) at the lowest level of segmentation. (b) Aggregated contrasting areas as super-objects (total extracted area is in red, consisting of aggregated objects delineated in blue).

For this study, the contrast calculations for 50 cm resolution takes place at the lowest level of aggregation where only single pixel objects exist (chessboard segmentation with leaf size 1).

Figure 3a displays different coloured classes for contrasting single pixel objects for panchromatic band with radius $d=1$ (yellow) and $d=20$ (green). The high contrasting pixels then serve as seeds for classifying super- objects, which must contain a certain minimal amount of contrasting single-pixel sub-objects. Figure 3a show the lowest level whereas Figure 3b shows the second aggregated level. The seed pixels (Figure 3a) are not enough to complete the aggregated objects at the second level (Figure 3b). Additional spatial relationships, Band-Ratio values and the factor "Zabud" (Lewinski, 2006) complete the classification of contrasting aggregated objects on the second level (Figure 3b).

The use of seed pixels in the lowest level of single pixel objects is mainly (but not exclusively) located in settlement areas. The positive role of contrast in settlement detection on the five meter resolution of RapidEye cannot be transferred directly towards the 50 centimetre resolution. The seed pixels for high contrast on near and far neighbourhood lead to a result which requires a confrontation with ground truth or an additional GIS.

The aim of this study is to use contrast mapping in the detection of artificial areas within an agricultural environment. The database on agricultural parcels is not aimed at mapping build-up areas. To prove that contrast mapping and build-up areas are associated, additional information is required with a reliable amount of specifically mapped build-up structures. Ideally an extensive digitalization project creating specific objects of interest for the assessment would be made available. However within the design of this case study, such (expensive) reference is in this initial stage replaced by cheaper alternatives derived from the existing topographic map information.

As high contrast is a non-exclusive characteristic of build-up areas, the commission errors are likely to occur with contrasting areas inside agricultural parcels, which are mainly induced by machine activity on bright-open as well as compacted soils. The assumption is that direct local contrast is responsible for commission errors in open soil but the incorporation of large neighbourhoods in contrast analysis differentiates between contrasting open soil and artificial areas. This is due to the variability among thousands of pixels within the search radius that differs over build-up areas in comparison with agricultural parcels.

While the factor $d=50$ has been useful in RapidEye analysis (5 meter), larger values for d require additional calculation time. As a single tile (4000x4000 pixels) in RapidEye needs 3 hours calculation time, whereas a reduced $d=20$, for a GeoEye (0,5 meter) tile (4000x4000 pixels) delivers a result in 20 minutes with sufficient contrast seeds to allow the analysis.

3. ASSESSMENT ON CONTRAST MAPPING

The bottleneck in the assessment remains with the limited availability of good reference data. Although GeoEye imagery has been processed for various European member states, only a few test sites have additional high quality topographic data readily available. For the selected Dutch test site, the scanned topographic map at 25:000 scale is available (called the Topo25). The Topo25 map exists only as a raster map including the black annotation. Separating the annotation from building footprints is regarded a tedious work on this scan. To design an assessment with this data type, at first an explanatory situation is presented using a local town where new build-up area on a meadow is visualized (Figure 5a,b,c). This shows a selected part of a GeoEye image over a Dutch village. The confrontation of the contrast area detection and the Topo25 can therefore lead to a limited amount of conclusions. Figures 5a, b reveal that a meaningful confrontation between the Topo25 and the detected contrast area is possible. In general, if the Topo25 contains a build-up area footprint, the contrast map derived from GeoEye is expected to cover it. It also increases the credit for the contrast area detection if it is not triggered when a building indeed has disappeared in the new satellite image while still being registered in the Topo25. This hints at the case that the contrast map is not excessively covering the whole area. Based upon an extreme case (an urban area extension) as displayed in Figure 5a, b, a scenario can be developed for an asymmetric assessment to the contrast area detection. (Asymmetric in the sense that the Topo25 raster map is used to confirm the association of build-up area with object based contrast detection and delivers a value for failure of omission.) With a very low value for the failure of omission, it can be assumed that contrast mapping is useful to detect build-up structures in general but also inside agricultural fields. After proving the usefulness for contrast analysis in detecting artificial areas, other vector datasets on agricultural parcels are used to achieve an insight in commission failures of this contrast analysis.

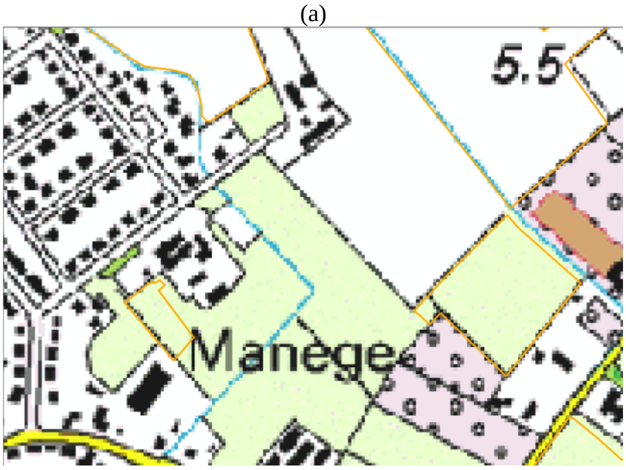
3.1 Area Flagging

Within the context of artificial area detection in the agricultural domain, the most important result of the automatic classification is the flagging of an agricultural parcel containing an artificial structure. The final delineation of a build-up surface into the object database continues to rely on a visual interpretation. As shown in Figures 5a, b, a new city block construction on agricultural areas can be detected. The layouts of the detected contrasting objects are not generalized. In their present condition they cannot be transferred directly into the database containing building-footprints. Figure 6a illustrates the confrontation between automatically detected objects and the building footprints registered in the topomap. Normally the detected contrasting object area covers and exceeds the registered building footprints (in Topo25).

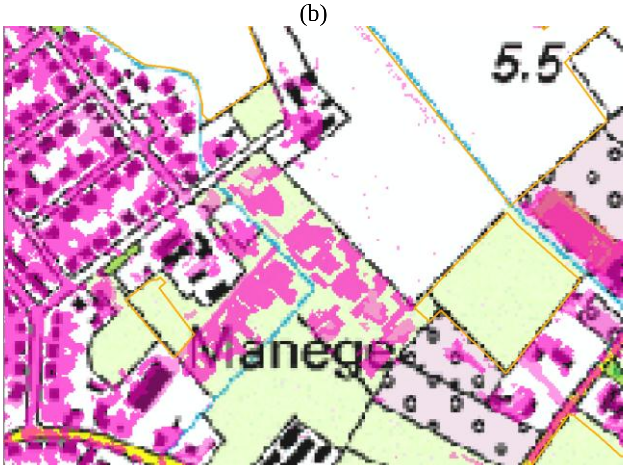
There are 8 situations in this confrontation:

1. A building is found as contrasting object and the detected area overlaps/intersects the building footprint.
2. A contrasting object covers an artificial area confirmed in the image but the footprint is missing. Topomap needs an update on additional building footprints.
3. A footprint is not covered by a contrasting object and the building exists in the image. (Omission error).
4. A footprint exists but is not covered by a contrasting object and the building does not exist anymore in the image. This is not an error but an update in topomap is necessary: the corresponding footprint needs to be deleted.
5. A contrasting object exists but does not cover a footprint. In addition there is no artificial area in the image. (Commission error/ false alarm)
6. A contrasting object covers an existing footprint but there is no artificial structure in the image. Hence a commission error related to a necessary update in the topomap. (However, this is an exceptional/theoretical event not occurred in this study).
7. A building exists in the image but it is neither detected nor present in the topomap. Potentially, this may happen especially for very small objects (such as dog kennel, tool storage) or for moveable objects like shipping containers.
8. There is no contrasting object-footprint and no artificial area in the image.

(a)



(b)

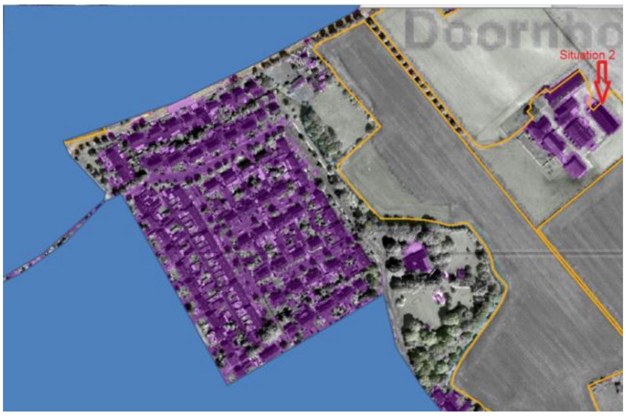


(c)

Figure 5. (a) Contrasting area detection (magenta) draped over GeoEye panchromatic imagery. (b) The 1:25:000 topomap of the same area, where black rectangles indicate registered buildings. (c) Contrasting areas (magenta) overlain on the 1:25.000 topomap. This reveals new structures built on green meadow (in the middle) detected in the GeoEye image whereas building footprints are absent in the topomap (absence of black rectangles) (**situation 2**).

When **situation 1** appears for the largest majority of the building footprints, it can be expected that the contrast assessment will respond to an artificial structure also inside the agricultural domain. Starting with a visual assessment of **situation 1** with about hundreds of hits per square kilometre, this will confirm first the applied algorithm on contrast detection in GeoEye coincides with the building footprints.

(a)



(b)

Figure 6. (a) Contrasting objects (magenta) draped on the 1:25.000 topomap, containing 83 building footprints in black. (b) Contrasting objecst (magenta) on the GeoEye image. A new building exists at the top right of the image (**situation 2).**

To demonstrate the procedure on the detailed visual interpretation, Figure 6a displays 83 building footprints which are either completely covered or partly touched (2 cases) by a contrast object area (magenta). For these 83 cases the **situation 1** exists. For an assessment of this image, all building footprints need to be summed up and visually assessed if they are covered or touch/overlaid on a building footprint. Additionally a visual check draped on top of the original Panchromatic GeoEye image (Figure 6b) displays only one **situation 2** contrast object exists.

The 80 km² of available GeoEye imagery over the Netherlands is analysed in tiles of 2x2km² blocks. For a randomly selected 2x2km² block partly including 2 villages (Figure 7), the **situation 1** exists for 1052 out of all 1060 building footprints where 5 of them belong to **situation 4**. Additionally **situation 2** (in the same block) occurs 95 times. There are also 3 types of **situation 3** omission errors, partly due to vegetation coverage. The latter confirm that with 0.3% omission failure, contrast mapping can be used to flag built-up areas.

The rare occasion of **situation 3** per square kilometre confirms that the contrast detection rarely misses a build-up structure and the total contrast-area "dendrite fairly covers the settlement areas (see Figure 7). Figure 6 is a detail from Figure 7. However, this procedure also produces a larger amount of commission failures which will be assessed next.

Figure 7. A typical dendrite of high contrasting areas (in red) over a Dutch village in one of the twenty six 2x2 km^2 blocks. Omission failures are less than 1%.

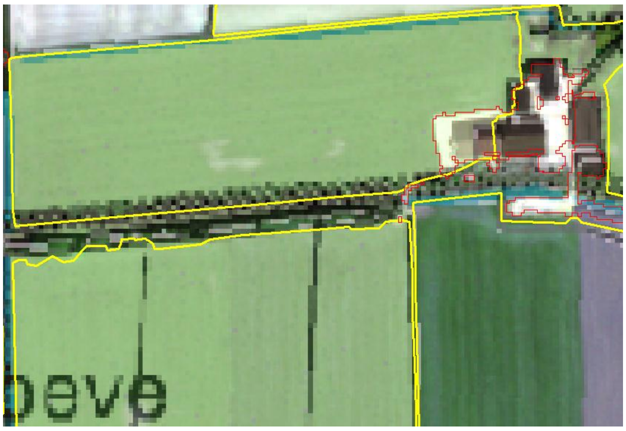


Figure 8. A typical **situation 2** (1 of 24 occurrences) inside a registered parcel. Yellow outlines registered agricultural parcels, whereas red outlines extracted artificial surfaces.

For the specific application of detecting artificial areas inside existing agricultural parcels, the **situation 2** is most common due to the construction of the database of agricultural parcels. This agricultural database, in general, does not cover settlement areas and should exclude buildings during its construction. Newly constructed build-up areas inside those parcels appear in recently acquired image and make a continuous updating of the database necessary. The **situation 2** involves also new buildings and infrastructure that are under construction since the last edition of the topomap.

The detection of **situation 3 and 5** is easier when dealing with topographic vector data. However, here the Topo25 is a scanned raster map. The separation of the building footprints from the annotation layer is cumbersome and makes a simple GIS intersection impossible. The assessment of omission and commission failures therefore currently depends on visual interpretation of selected blocks. The available building footprints of the Topo25 for the selected blocks are a start for assessing this type of result but it comes with limitations. For a quantitative analysis of the total study area, a special reference of digitized artificial areas and its use as assessment layer (an additional GIS layer with up to ± 1000 building footprints per square kilometre) is necessary. However, this is beyond the scope of this paper since the aim is limited to correctly "flag" agricultural parcels. With only 795 selected agricultural parcels in total study area it is possible to assess the **situation 2** flagging within these parcels only, using the limited reference available. There are 795 parcels on the 80 km² study site. The WikiCap (2011) describes a surface larger than 100 m² of ineligible area requires an update of the parcel. For 143 parcels, the contrasting area is equal to or exceeds the 100 m². Detailed inspection reveals that 24 parcels should be re-evaluated on eligibility due to new build-up constructions (see Figure 8) and 14 parcels have dubious contrasting areas but still might be eligible. This leaves 143-38= 105 commission errors **(**13%).

4. CONCLUDING REMARKS

Contrast is a characteristic feature for urban and artificial areas. The contrast analysis can be used to "flag" areas in need for map update. This can cover the topographic map update but also special GIS databases such as the one designed for eligible agricultural land. The scale factor is prominent. Using GeoEye imagery, contrast over large neighbourhoods is only achieved for parts of build-up structures (contrary to 5m resolution where it is possible to extract build-up structures completely). The whole building delineation thus depends on contrasting seed pixels which are an important part of the solution but aggregation of seed pixels to cover complete build-up areas is still necessary.

For the purpose of artificial area detection in agriculture, the largest class of commission errors is linked to open soil and agricultural management practice, especially where tree-shadows cast over open soil. These dynamic areas are under continuous change, related to vegetation cover, in different periods of the growing season. Reducing further on commission failures might then be possible using multi-temporal dataset allowing even lower resolution and therefore cheaper imagery.

With an extensive very high resolution coverage at national level, such as recently developed by the BING maps strategy, full automatic priorization of areas relevant for map update might become more and more a necessity. Contrast mapping can contribute to this.

5. REFERENCES

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