Mapping and Monitoring Airports with Sentinel 1 and 2 Data
Urban Geospatial Mapping for the SCRAMJET Business Networking Tool

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Abstract: SCRAMJET is an online tool that allows business travellers to connect and plan to meet in any of the airports included in their trip. To successfully deliver, SCRAMJET needs accurate and up-to-date worldwide airport mapping information. This paper describes an assessment of the use of Earth Observation (EO) products, in particular the Sentinel program, for improving airport mapping and monitoring its changes. The first step is to verify the data availability of Sentinel-1 and Sentinel-2 at a global scale, and then evaluate its adequacy for airport mapping. For monitoring airport changes, the analysis tested multispectral change detection methods and interferometry processing techniques. The main conclusion was that the acquisition frequency of both Sentinels is a great benefit to assure up-to-date information at a global scale. The recommended approach for a target of 200 airports is to do the airport mapping, assisted by Sentinels data for validation and improvements, and monitoring changes by integrating a Sentinel-2 change detection chain (using NIR/SWIR bands), in parallel with OpenstreetMap change detection processing.

1 INTRODUCTION

SCRAMJET is a web and mobile product to connect business travellers at airports that is being developed by WATERDOG at ESA BIC Portugal. One of the key assets of the tool is to maintain reliable, updated and accurate airport maps to ensure travellers can agree on a meeting point while planning their trip and, once physically at the airport, find each other. The maps comprise both indoor and outdoor features, including the buildings' morphology, gates identification and Points of Interest (shops, toilets, etc…) as depicted in figure.

Figure 1: Outdoor and indoor mapping needs.

The typical usage scenarios of the maps are:

- The user knows his gate and the gate of the person to meet and uses the map to choose the meeting place, for example Gate 21 or a coffee shop POI ;
- The user lands and a location-based tool running on his phone provides rough indoor guidance visually identifying the place to go.

SCRAMJET will have its own airport map information and the research presented in this paper is crucial for two development and maintenance needs:

- **Airport Mapping**: the initial geographical information of all airports is obtained from OpenstreetMap (OSM) and Google Maps is used for validation. Nonetheless, many airports have incomplete or outdated mapping data on these platforms that needs to be validated and improved.
- **Monitoring the Airport Changes**: airports may be subject to works, renovations and extensions that need to be detected.

The available literature on automatic airport mapping and monitoring from remote sensing image data is very scarce. First, previous works on automatic airport mapping mainly focused on the runways detection as they are the primary characteristic of an airport. Wang et al. (2013) used a Hough transform to judge whether an airport exists

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in a Very High Resolution (VHR) image. Then a scale invariant feature transform in conjunction with a hierarchical discriminant regression tree was employed to detect the airport area. Aytekin et al. (2013) used a texture-based runway detection algorithm that uses the Adaboost machine learning package for identifying 32x32 pixel image tiles as runway or non-runway. Second, for automatically monitoring the airport changes, Digital Change Detection algorithms that provide binary land cover “change/no-change” information, can be used (Jensen, 2015). In fact, by automatically detecting the spatial regions within a bi-temporal image pair where meaningful change is likely to have occurred, a human operator (or another process) can then analyse the changes using his/her knowledge.
ESA’s Sentinel missions are providing us with reliable and timely open data on land, ocean and atmosphere with high spatial and temporal resolutions for state-of-the-art research activities and services, e.g., natural resources management and urban land cover mapping (Malenovský et al., 2012). In this context, synergetic use of Sentinel 1/2 data has been used for urban land cover mapping and change detection (Ban et al., 2017; Haas and Ban, 2017). Although the potential of Sentinel 1/2 data has been highlighted in the above works, the effective use of this data in the context of mapping and monitoring airports need to be assessed.

This study aims to confirm the needs and verify how Earth Observation satellites, in particular the latest Sentinels satellites, can be used to assure the best up-to-date outdoor mapping for an initial target of 200 world airports. The work assesses the temporal and spatial suitability of Sentinels (or other EO data) and defines a service chain design for airport mapping and monitoring changes.

2 EO DATA AVAILABILTY

The first step of the analysis was to confirm the temporal availability of EO data at a global scale, by defining a timeframe for validation on a set of worldwide airports.

The selected timeframe was the latest two months before the study started, from 1st December 2016 to 31st January 2017, while nine airports were chosen, representative of different geographical regions from USA, Europe and Asia.

During this period, two Sentinel-1 (S1) and one Sentinel-2 (S2) were operational. The Sentinel-1 (synthetic-aperture radar) was operating with S1A and S1B satellites, while the Sentinel-2 (multispectral) had only the S2A satellite active (S2B was launched just on 7 March 2017).

The data procurement results of Sentinel-1 (S1) and Sentinel-2 (S2) on these airports are presented in the table.

Table 1: Sentinels data availability.

		Sentinel-2	Sentinel-1
Europe	Lisbon	S2A 2016-12-19	2017-01-19 (S1A IW VV-VH)
	München	None (dense cloud coverage)	2017-01-25 (S1A IW VV- VH)
	Istanbul	S2A 2017-02-02	2017-01-14 (S1A IW VV-VH)
	Malaga *	S2A 2016-12-20	2014-11-27 (S1A SM HH-HV)
USA	Atlanta	S2A 2016-11-28	2017-01-06 (S1A IW VV-VH)
	NYC/JFK	S2A 2016-12-04	2017-01-12 (S1A IW VV-VH)
	Miami	S2A 2017-01-06	2017-01-01 (S1A IW VV-VH)
Asia	Ben Gurion	S2A 2017-02-10	2017-01-04 (S1A IW_ VV-VH)
	AbuDhabi	S2A 2016-12-25	2017-01-07 (S1A IW_VV)
	Shanghai	S2A 2017-01-29	20170122 (S1A IW VV-VH)

S2A has visible data from almost all airports, including the 4 relevant bands for this study with 10 m spatial resolution: B2, B3, B4 and B8.

Figure 2: S2A True colour composition.

S1A and S1B were also capturing data in all airports but using different modes. The main operational mode for land is Interferometric Wide (IW) High Resolution, typically using single or dual polarization, with a spatial resolution up to 25 m. The best resolution mode is Stripmap (SM) Full Resolution, with a spatial resolution up to 10 m, that is used only on request, typically on extraordinary events, such as emergency management. Both acquisition modes are available in the SLC product format, needed for interferometry applications, and GRD product format that is geo-referenced from SLC.

The acquisitions in IW mode were widely available for all nine airports selected. Malaga* airport was the only aerodrome found, acquired in Stripmap mode Full Resolution and thus was added to the baseline.

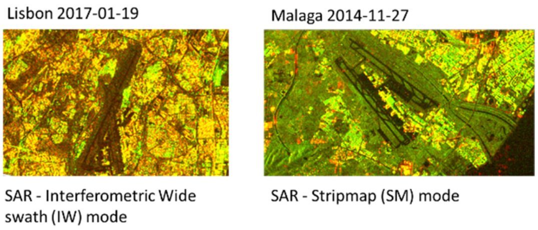

Figure 3: S1A IW VH-VV and SM HH-HV RGD compositions.

2.1 Satellite Open Data Availability

Considering the technical specifications (namely the spatial and temporal resolutions) of the SCRAMJET two different open satellite data products have been identified as the most useful: Sentinel-1 and Sentinel-2 data. Concerning the Sentinel-2 data, it was found that:

- Temporal frequency of Sentinel2 is fine. During the selected timeframe S2A captured in average 1 good quality image per month, and there are good images available in 90% of the airports.
- S2B was launched on 7 March 2017 and will increase temporal availability.
- It may be difficult to capture images during winter season in some airports (e.g. Munich, Atlanta) due to high dense cloud coverage.
- Airports on the intersection of granules or tiles need to have a special handling, such as JFK that is right on the intersection of 4 granules.

Regarding the Sentinel 1 data, it was found that:

- IW acquisitions are available for all the 9 airports in dual polarization VV-VH excepting in Abu Dhabi that acquisitions are done in single VV polarization.
- Very few Stripmap (SM) Full Resolution images are available at the archive. The ones found were acquired from special zones, namely the Strait of Gibraltar and a region of Germany.
- Almost all acquisitions are available in both SLC and GRD product formats.

Other open satellite data procurement, in particular Landsat8, was dropped since the first results pointed that S2 has better spatial resolution.

3 AIRPORT MAPPING

The adequacy of the available data to meet the mapping requirements was performed focusing on spatial and spectral resolution and on the quality of OSM data. The initial analysis covered only Sentinels but it was later extended to analyse commercial solutions. The three airports (Lisbon, Istanbul, Abu Dhabi), used as analysis baseline, were thus extended to Malaga and Malaysia in order to address relevant data found on these areas.

3.1 Mapping with Sentinel-2

Three airports were selected for study from the initial nine: Lisbon, Istanbul and Abdu Dhabi. The approach was to build RBG composites with the better resolution bands, layered with existing Points of Interests from OpenstreetMap.

In the Lisbon airport, the S2A image was composed with OSM data (Fig. 4), resulting on the following findings:

- The visibility is slightly blurred. It is hard to identify planes and gates.
- Many gates are mapped in OpenstreetMap (20 "aeroway"=>"gate, 1 "aeroway"=>"helipad")
- Infrared composition in Lisbon during winter, (with more intense the grass) may be an advantage to identify airport morphology

Figure 4: Lisbon S2A true colour composition with OSM.

Regarding the Istanbul airport, the S2A image depicted on Fig. 5 highlights that:

- Although it has good visibility, additional support photos and maps need to be used for mapping
- The gates identified by red polygons are not available on OSM

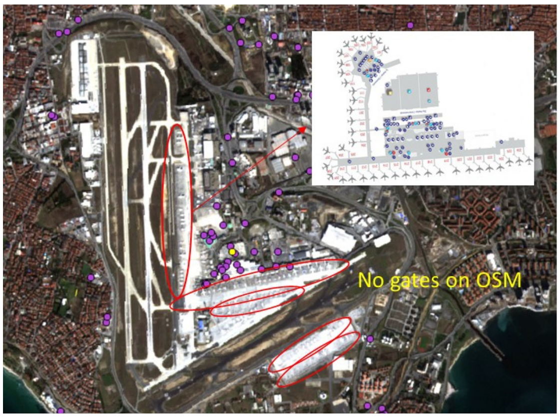

Figure 5: Istanbul S2 true colour composition with OSM.

The Abu Dhabi airport (27th in Asia) was selected, not being as busy as Dubai International Airport (3rd in Asia). The S2A image composition on Figure 6 concludes that:

- It has very good visibility: parked airplanes the new gates under construction are visible
- 41 gates are mapped in OSM (new gates were not yet available in OSM)

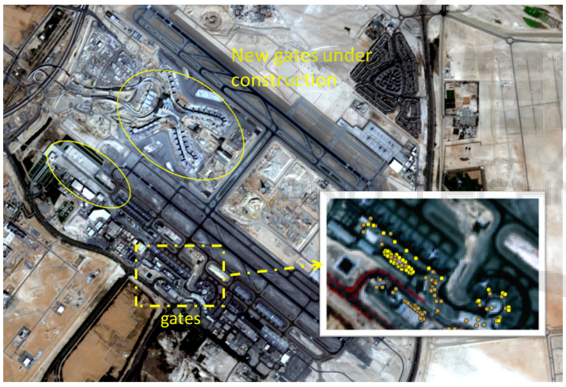

Figure 6: Abu Dhabi S2 true colour composition with OSM.

3.2 Mapping with Sentinel-1

Two study areas were analyzed: the Lisbon airport using images acquired in the default Interferometric Wide mode High Resolution and the Malaga airport acquired in Stripmap mode Full Resolution. After performing the geo-corrections of both S1A GRD products, a RGB composite was produced with two polarization bands (refer to Malaga RGB composite on Fig 7).

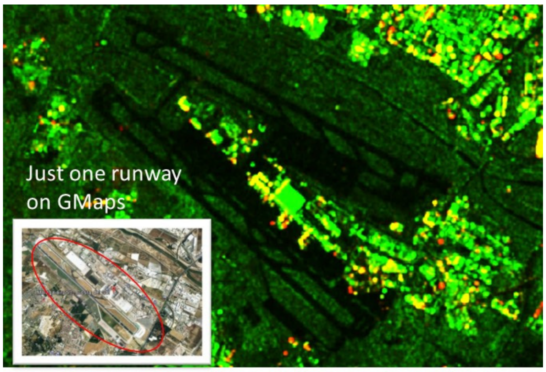

Figure 7: Malaga S1A SM HH-HV RGB compositions.

The analysis concluded that:

- Both modes allow a good identification of building areas and runways. It allows to easily identify that Google Maps was showing an outdated image of Malaga airport, with a single runway, acquired before expansion on June 2012.
- S1A Sripmap FR (Malaga) has a more appropriate spatial resolution than S1A IW HR (Lisbon).

3.3 Mapping with Non-Open Eo Data

Considering that Sentinels may not have enough spatial resolution for the needs, alternative commercial satellite data with better resolution was analysed. The project identified two very high-resolution solutions from Pléiades (0.5-m) and Deimos-2 (1m-4m) with competitive prices. An example of Langkawi Airport at Malaysia using Pléiades from 2017 is provided in Figure 8.

Figure 8: Malaysia Pleiades true colour composition.

The analysis concluded that:

- Pansharpened images with 50 cm resolution and 4 bands offers excellent details of the airport, allowing recognition of the planes types

- Temporal acquisition is not as flexible as Sentinels at cost-effective prices

3.4 Mapping Sources Analysis

The analysis highlighted that there is no single solution for all sites as presented in the table.

Table 2: Analysis of the airport mapping sources.

	S2	S1	Pleiades	OSM
Lisbon	Blurred	Low resolution (IW)	N/P	20 gates
Istanbul	Good visibility	N/P	N/P	No gates
Abu Dhabi	Very good visibility	N/P	N/P	41 gates
Malaga	N/P	Good resolution (SM)	N/P	N/P
Malaysia	N/P	N/P	V High resolution	N/P

The best and relevant mapping sources depend on the particularities of each site. The conclusions per mapping source are presented below:

- Sentinel-2 images may be used to support morphology and gates visual mapping and validation. The spatial resolution may be just on the limit. Acquisitions with good visibility are fine for gates but hardly recognize airplanes.
- Sentinel-1 can also support the identification of runways and build-up areas, but GRD IW High Resolution products have a spatial resolution less than 25 m.
- Some cases may need commercial very high-resolution images.
- OSM does not offer a complete mapping solution on all cases analysed. Not all airports have gates identified in OSM.
- Additional support photos and maps may be used for morphology and gates. Note that Airport Buildings do not have clear boundaries. They are often confused with surrounding buildings (hotels, etc…).

The mapping conclusion is that the acquisition frequency of Sentinel is a great benefit and the solution shall definitely be based in a combination of different sources.

4 MONITORING THE AIRPORT CHANGES

The usage of the change detection methods could be useful to trigger airport morphology changes. The two typical binary land cover changes that we want to detect are:

- Urban to Demolition
- Null Soil/Vacant Land/Demolition to Urban

In this context, two detections approaches were evaluated:

a) Change detections with Sentinel-2: detect abrupt changes using image pairs, before and after the event, and a reasonable number of pixels (between 9=3x3 a 25=5x5).

b) InSAR with Sentinel-1: use an InSAR technique to detect surface deformations upon analysis of the phase difference between two radar signals acquired from the same area at different times. The usage of Advanced InSAR for the identification of hotspots subsidence at airports was kept in standby at this stage. Although it may resolve millimetre-scale movements of infrastructure, the usage of multiple images was considered having high costs (storage and computation).

4.1 Study Area

The area selected for testing was the Rio de Janeiro airport, which was renewed for the 2016 Olympic Games. The works started in 2014 and finished in Abril 2016.

Figure 9: Google Maps historical data of Rio de Janeiro airport.

The gates were extended with a new area and more car parks were constructed.

4.2 Detecting Changes with Sentinel-2

The pair of S2 images selected for testing were the first cloud-free image available from this airport (Fig. 10): one image was acquired in 2015 during renewal, and the other in 2016 after renewal.

Figure 10: Sentinel-2 images used in change detection.

For change detection using a pair of images three main categories of methods could be used:

- Simple Detection: use Mean Difference, Ratio Of Means or Root Mean Square Differences of the relevant bands (typically visible and near infrared bands 2, 3, 4 and 8)
- Normalized index change detections: produce normalized indicators related to built-in areas (using S2 bands) and compare them. The most relevant index is the Difference Built-up Index (NDBI) applied in Landsat TM with SWIR1 and NIR bands (Zha et al., 2003).
- Post Classification Comparison: make supervised classification of the pairs and compare results (e.g. land cover comparison, Built-up Areas comparison)

In this paper, only the first two categories were analysed and presented hereafter. Post Classification was abandoned since it was considered more relevant with global and regional scales (world, country, regions) rather than local scales such as the airports gates details.

Ratio of Means Detection with NIR Band

This analysis started by using simple detectors. The ratio of means was firstly used with NIR band (B8) from Sentinel-2.

$$I\ (i,j) = \frac{I2015\ (i,j)}{I2016\ (i,j)}$$

The achieved results were quite acceptable, allowing to easily identify the new gates area and the reconstructed car park that was not initially identified during google maps inspection.

Although this detector was successfully applied on Rio airport study area but it needs to be bounded and normalized to be applied widely on other airports:

$$I\ (i,j) = 1 - \min\left(\frac{I2015\ (i,j)}{I2016\ (i,j)}, \frac{I2016\ (i,j)}{I2015\ (i,j)}\right)$$

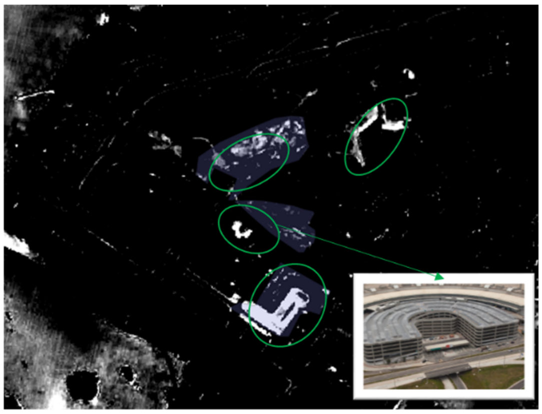

Figure 11: Change detection with NIR.

Ratio of Means Detection with SWIR Band

The second approach was the ratio of means using the SWIR band (B11) from Sentinel-2. Although this band has lower spatial resolution, the results achieved are also quite acceptable.

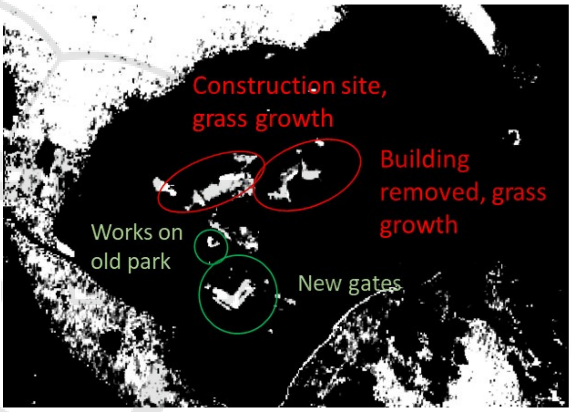

Figure 12: Change detection with SWIR.

Note that this detector needs also an improvement in order to be bounded and normalized.

Root Mean Square Differences Detection with 4 Bands

The third detector was the Root Mean Square Differences computed with the visible and near infrared bands (B2, B3, B4 and B8). Because the obtained results are unclear, it was dropped.

NDBI Index Detection

The last multispectral detector was the Normalized Difference Built Index (NDBI), which is referred in the change detection literature as a promising method (Jensen, 2015; Zha et al., 2003). For its usage with Sentinel-2 imagery, the S2 SWIR and NIR bands were used as follows:

$$NDBI\ (i,j) = \frac{SWIR\_B11\ (i,j) - NIR\_B8\ (i,j)}{SWIR\_B11\ (i,j) + NIR\_B8\ (i,j)}$$

Nonetheless, the change detection results with NDBI 2015 and NDBI 2016 obtained confusing results.

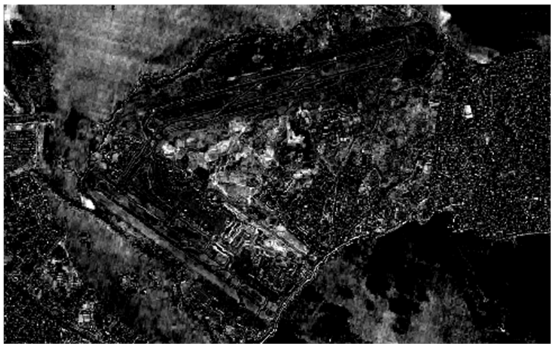

Figure 13: Change detection result with NDBI 2015-2016.

The change detection conclusion was that simple detectors with NIR and SWIR bands could solved the problem on this study area. The usage of these bands shall be further verified and confirmed on other airports. The usage of spectral unmixing techniques at pixel level with significant changes on land cover could be an alternative approach for a future analysis to fine-tune the detections.

4.3 Interferometry Processing with Sentinel-1

For the analysis of the interferometry processing, a pair of Sentinel-1 images from 2015 and 2016 were used. Both images were acquired in IW mode with dual polarization VV-VH (Fig. 14).

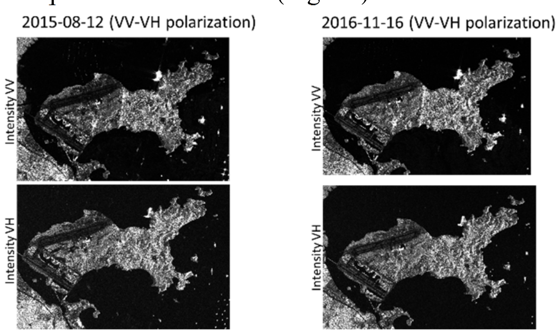

Figure 14: IW product pair used in change detection.

The GRD products were used to produce a RGB colour-composite from VH and VV polarization images. The composites allowed to identify the extended gates in 2016 (Fig 15).

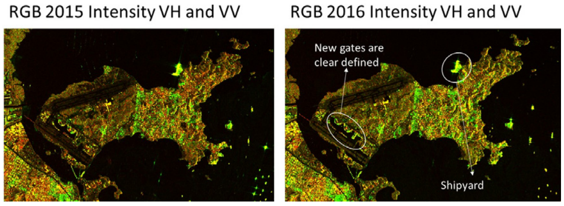

Figure 15: RGB composition of S1A IW VV-VH pair.

The SLC products were used for the interferometry processing. The pair of products were captured in IW mode with three sub-swaths (IW1, IW2 and IW3) using Terrain Observation with Progressive Scans SAR (TOPSAR). The SNAP (Sentinels Application Platform) tool was used, following TOPS Interferometry Tutorial (Veci, 2015). The co-registration of IW1 relevant sub-swath was performed, the interferogram was produced, the topographic phase was removed and the phase filtering was applied. The interferogram results after the ellipsoid correction are in the figure below.

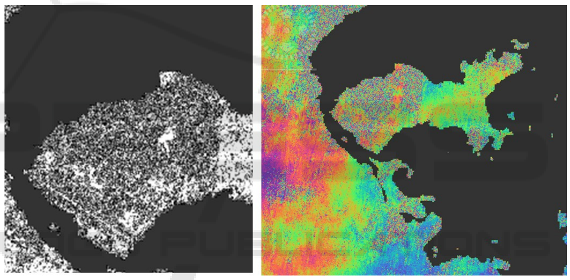

Figure 16: Coherence and phase interferogram 2015-2016.

The results were not effective. Although the interferogram requires a detailed interpretation, this preliminary analysis did not spot relevant changes on coherence and phase interferogram. Additionally, the spatial resolution of the IW acquisitions may not be sufficient for the monitoring cases.

5 CONCLUSIONS

The study confirmed that several OpenstreetMap and Google Maps information of the airports are incomplete or outdated. Although, Sentinels lacks spatial resolution, they can be an advantage to validate and trigger mapping improvements. The acquisition frequency of both Sentinels is considered a great benefit to assure up-to-date information at a global scale.

The recommended SCRAMJET approach for a target of 200 airports is to do mapping assisted by Sentinels and eventually other commercial EO data, and to monitor changes using a Sentinel-2 semi-automatic change detection method.

Mapping

The mapping solution shall be definitely based in a combination of multiple sources, including OpenstreetMap, Sentinels, Google Maps, local photos and other commercial EO data.

The system shall extract the relevant OSM data to create an initial mapping information. An extended EO chain (Figure 17) is recommended with automatic data acquisition and pre-processing of Sentinels data. The Sentinels data shall be used for mapping validation and trigger improvements based visual inspection of Sentinels and other complementary sources.

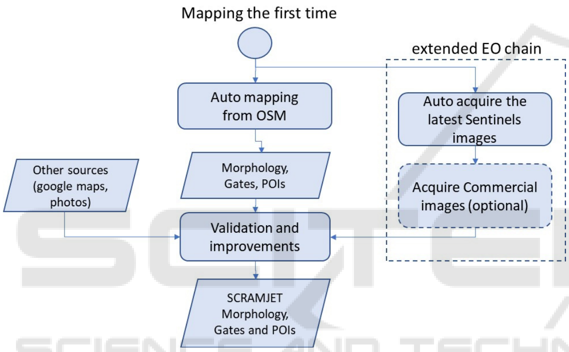

Figure 17: Mapping solution with EO extended chain.

Monitoring Changes

The foreseen solution is also to integrate extended EO change detection with the OSM change detection, checking changes every 3 months as depicted in Figure 18.

The semi-automatic change detection with Sentinel-2 is suggested, taking advantage of its update frequency. Implementing an automatic detections is technically feasible to generate alerts but it will require a visual inspection to confirm and trigger the updates. The change detection algorithm needs to select cloud free images, normalize the processing and finally fine-tuned algorithm with a wide number of airports to become fully automated. The automation shall consider the costs of creating EO baselines (storage) and processing EO images (computing).

The changes detected with S2 are real and faster but they will probably include many false positives while the changes detected from OSM are more accurate but more delayed.

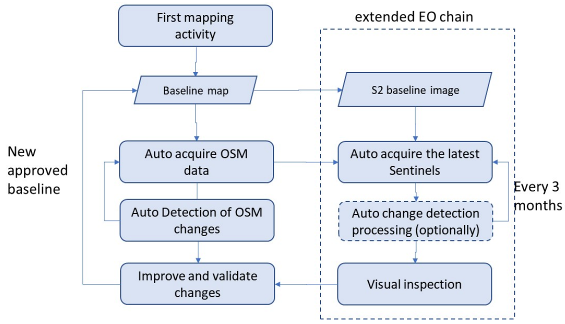

Figure 18: Monitor changes extended with S2 detections.

An initial automated proof-of-concept to validate the study conclusions is recommended as a next step. A pilot with 3-4 airports shall start by automating data acquisition and pre-processing for mapping purposes. The change detection processing chain with NIR and SWIR bands shall be further analysed with alternative approaches and automated afterwards in order to start collecting results and to fine tune the algorithm.

Figure 19.

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