Future Benefits of Micro Satellite Constellation Images for Railway

Claire NICODEME (1)

[1] SNCF, French Railway Company, 1-3 Avenue François Mitterrand, 93574, Saint Denis
Email: claire.nicodeme@sncf.fr

KEY WORDS: environmental surveillance, disasters prediction, railway, artificial intelligence

ABSTRACT: The first satellite to be launched was Spoutnik-1 in 1957, in a global race to control communication transmission. Since, many improvements were made, widening the potential applications of this technology. Today, about 2.100 active satellites are orbiting the planet. They are designed for Navigation, Telecommunication or Remote Sensing. Earth Observation satellites are in Low Earth Orbit (LEO), at an altitude between 500 and 2000km. This strongly reduces latency in data transmission, enabling near real-time precise observation.

Nowadays, the French railway company uses satellite images for different purposes. First, they track vegetation growth (one or twice a year) and organise pruning consequently. Second, they evaluate the impacts of heavy rains on soil humidity, as mud slide or stagnant water close to rail tracks. The Indian Railways has undertaken the mapping of the entire railway asset infrastructure (first mapping the entire track network, second mapping railway land and other assets along the tracks). Pakistan and Netherlands have also published their work on the subject (2012 and 2014).

Existing applications show that at the moment, satellite data are only used to follow the evolution of the environment, non-real-time. The information could be obsolete. Worse, in case of Natural Disasters, images are given tardily, which waste precious time for people in need of assistance.

This paper aims at evaluating the impact of LEO satellite constellation (SC) for railway industry and wider uses. The hope is that LEO SC will share in making a smarter transportation system and improving reaction to unattended situations.
Note that we focus here on Earth Observation Satellite (EOS) constellation but telecommunication constellations are also to be inquired into.

Micro-satellite constellations (MSC) could create a network, covering the entire planet at any time. A continuous watch would offer the possibility of frequent tracks and infrastructure map updates or the supervision of construction sites and their ecological impacts (water and soil pollution). MSC would allow trains tracking especially on secondary tracks, with less ground equipment. Last example, satellite constellation images and AI could provide prediction of natural disasters (earthquake, tsunami, flood, etc.) and their evolution. It would help better prepare for and respond to disasters by positioning materials and resources. For trains it means the possibility of evaluating the condition of tracks and infrastructure to adapt traffic management, ensure safety and plan maintenance.

Railway is the greenest transportation system, this industry has to evaluate the ecological impact of using such technologies: first the hardware construction, second the energy consumption of processing such enormous volume of data. The latter will also impact the delay between acquisition and alert if an unusual event is detected.
This technology has become affordable and accessible. Yet, due to reduced lifetime of LEO micro-satellite, more launches would probably be needed. Plus, for near-real time observation, say one picture every half hour, the size of the constellation have to be substantial.

Micro-satellite constellations for Earth Observation applied to Railway have a great potential. More developments and discussions with interested parties will be necessary to make it a reality.

1. INTRODUCTION

The late 50s saw the first developments of space activities. They were driven by political and military aspirations. It began in 1957 when Sputnik, the first artificial Earth orbiting satellite, was launched. Two years later, on August 14^{th}, 1959, the first satellite photographs of Earth were taken (NASA 2002). Since then, Earth Observation Satellites (EOS) experience a significant improvement every twelve to thirteen years.

The first three operational satellite imaging systems, CORONA, ARGON and LANYARD, were operated in the context of the Cold War. They used photographic film with a canister return system (BELWARD 2015) to record images for detailed reconnaissance purposes and regional mapping. The spatial resolution was >100m, with a ground swath over 500km². The second generation represented by LANDSAT-1 in 1972 provided Earth images with better resolution (80m). The revisit time was as short as eighteen days and data were delivered directly in digital form. It made it possible for scientists to study Earth resources more accurately (ZHOU 2002). In 1986, SPOT-1 embodied the next EOS. It used the first push-broom space sensor with a 10m panchromatic resolution. In addition, the active microwave sensors helped improve the understanding of environmental and climate phenomena.

Until the late 1990s, the primary consumer of remote sensing data was either governments or defence agencies (RUFFNER 1995). The launch of IKONOS, the first commercial satellite, in 1999 opened a new era of high-resolution satellite imagery. Many applications started to rise such as mapping (TAO 2004), resource management (GOETZ 2003) or precision agriculture (SEELAN 2003).

The transportation area was not covered until the early 2000s. Satellite imagery was first complementary information to ground measurements. It is a snapshot in time of a relatively vast area. In 2005, (GERHARDINGER 2005) introduced the idea of the detection of vehicles in very high resolution satellite images. Indeed, very high resolution can be used for traffic management, emission estimation or planning transport infrastructure. This idea is trending upwards and several papers have presented their progress since (CAO 2016). China (XIE 2013, CAO 2017) and India (ABRAHAM 2014, GARG 2016) have a particular interest in the subject for they have very high traffic density in urban zones.

Regarding the railway, only few papers are available. The detection of rail tracks and the measurement of its instability from satellite images appear to be the few covered subjects. In 2014 for instance, a Dutch team (CHANG 2014, CHANG 2016) demonstrated the feasibility of monitoring the stability of the railway tracks using dedicated satellite radar observation. The aim was to spot damaged areas and help with reparations planning. They were able to detect mm-level deformations in the track geometry using InSAR.

All of the satellite missions described previously took place from the Low Earth Orbit (LEO). The principle is to place smaller and lighter satellites in orbit at a lower altitude (180-2000km).The selection of this orbit has several advantages such as cutting costs, reducing latency and increasing capacity. On the other hand, it reduces the coverage compared to geostationary objects, creating a need to densify the network. This last decade has witnessed a noticeable trend toward the development of both micro-satellite technology (<100-150kg) and the initiation of multi-satellite constellation projects. The consequence is an increasing number of active satellites.

In this paper, we offer an overview of the benefits of constellation images for the railway. The potential applications need a high frequency acquisition as well as a powerful and automated data processing, which are not available to date. The paper is organised as follows. Section 2 introduces the known satellite constellation projects. Section 3 highlights Artificial Intelligence (AI) contributions to satellite image processing. Section 4 describes how the railway could benefit from high frequency satellite images with the help of AI. Section 5 points out ecological challenges of such a solution, especially for a low carbon emission company.

2. SATELLITE CONSTELLATIONS

Current applications only exploit satellite data to keep track of past events. For instance, it is possible to witness the impact of a natural disaster: the amount of forest that burned in a fire, the land destruction after an earthquake or a tsunami, etc. The delay between the catastrophe and data accessibility strongly depends on satellite revisit time. Satellite revisit time or period is the time elapsed between two consecutive observations of the same point on Earth by a satellite. It depends on the satellite's orbit, target location and swath of the sensor (BRACHER).

As of today, optical satellites duo such as Pleiades have a daily revisit time (off nadir) and a repeat cycle of more than twenty-five days (at nadir). A single Worldview-3 is defined by a revisit time of less than a day and a repeat cycle of twelve days. For many other EOS, the revisit time can be three to five days. Hence, when an operator receives information, it could be obsolete. In particular, in the event of a natural disaster, images are received belatedly which may waste precious time for people in need of assistance. Higher frequency satellite images could help improve our preparation and response to disasters.

Table 1 - Non-exhaustive list of high frequency imaging constellation in 2019. Lightly coloured squares indicate that at least one functional satellite is in orbit. The Planet constellation (green) is already fully operational.

	RESOLUTION	NUMBER OF SATELLITES	FREQUENCY OF ACQUISITION
PLANET Flock/ Dove Skybox/Terra Bella	3.4 m 0.9 m	+150	Daily Earth Coverage
AXELSPACE	2.5 m	50	Daily Earth Coverage
BLACKSKY	0.9-1.1 m	60	21 To 36 Minutes (Area Dependant)
SATELLOGIC	1 m	25 300	2 Hours Refresh Rate 5 Minutes Refresh Rate
ADA SPACE	0.5-1-5 m	192	Minute-Level Updates
SATREVOLUTION	0.5 m	1024	30 Minutes Refresh Rate
HERA SYSTEMS	<1m	50	~ 1 Hour Refresh Rate
AQUILA SPACE Corvus HD Corvus BC	2.5m 22 m	30	Daily Earth Coverage
EARTHNOW	*Not available*	500	Live Stream Of The Earth

The 21st century saw rapid changes in the remote sensing industry. The fall in costs of satellite imagery contributed to the increase in data consumption. Open source data emerged with Landsat data becoming public in 2009. This led to the need for fast and automated data processing and interpretation which AI could provide. Its booming expansion has covered numerous subjects and scientific areas: transportation, medicine, banking, maintenance, security, etc. The benefits of AI algorithms have long been demonstrated. The spatial domain has not been spared by the AI expansion. Yet there is still a lot that could be done.

3. ARTIFICIAL INTELLIGENCE FOR SPATIAL DATA

Experts have been analysing individual satellite scenes for decades. Making satellites cheaper has led to the exponential increase of the daily amount of produced data (proliferation of satellites, improvement in camera technology, increase of data storage and transfer capabilities). The development of Big Data and Machine Learning (ML) algorithms allows analysing such data at a scale never seen before. This has given birth to a demand for AI-driven satellite data applications.

In the literature, ML is already applied to satellite images. Since 2009 (KUBAT 2009), papers have been presenting supervised learning (vehicle detection XIE 2013, urban pattern recognition WIELAND 2014, semantic annotation YAO 2016) and unsupervised learning (scene classification LI 2016) researches. Transfer learning (CAO 2016) is also under investigation, as well as discriminative learning (CAO 2017). Since satellite images are quite big, pre-processing (such as dividing the image into smaller tiles) is mandatory to keep satisfactory computational time. The enthusiasm for both space imagery and AI are rapidly drawing those two disciplines together. The author believes that this combination has yet a lot to offer.

4. POTENTIAL SATELLITE IMAGING APPLICATIONS FOR THE RAILWAY

Usually, satellite imaging sensors are divided into three groups:

1) **Optical sensors**: they reproduce the Earth's surface from light waves. It can help determine the location of objects and the extent of a given event.
2) **Synthetic Aperture Radar (SAR)**: they measure fine changes in the Earth's surface. It can detect mm-level altimetric variations. It is also possible to study structural weaknesses.
3) **Radiometers**: they measure atmospheric content and surface emissivity. It can be used to monitor events and produce maps.

Their combination with AI would allow predicting events, learning patterns from past datasets. Prediction helps improve preparation and organisation which would lead to more effective actions to respond to events.

Three major railway scopes are discussed here: trains surveillance and positioning, construction worksite surveillance, infrastructure monitoring.

4.1.Trains surveillance and positioning

Nowadays, freight convoy may happen to lose carriages. Some get detached and stop, blocking the tracks. It is also an annoying incident for a customer as it introduces delays. It is a necessity to be able to quickly find such isolated cars.

To date, GPS-based systems are only embedded in the engine car because of their high prices. To date, when a carriage gets separated from the rest of the train, there is no solution that gives its precise location. An overview of the rail network using satellite images could help detect and precisely locate missing carriages. An extension of this image-based train positioning could be to merge data from satellite imagery, GPS and Geographic Information System (GIS) to monitor and manage the assets across the country.

4.2.Construction worksite surveillance

Collection of accurate, complete and reliable field data is a necessity for an active management of construction projects. It would include material tracking, e.g. sleepers and rails, progress monitoring and the ecological impact surveillance. For instance, when digging a new tunnel, one has to be sure that it won't collapse. It is a possibility that the ground will slowly subside. Satellite images (e.g. InSAR) could alert of such unwanted ground movement and prevent a disaster. Another example is the follow-up of assets: the system would count the number of vehicles on the premises, indicate their location, check for missing machines, etc.

Current manual data collection approaches are limited (in terms of speed, completeness, and accuracy). It makes the high frequency space approach very appealing for decision support in highly dynamic environments.

4.3.Infrastructure monitoring

Rail tracks are one of the most important and central elements in the railway. Even a small damage in the infrastructure may have disastrous consequences. Moreover any object or material in the train's gauge could put passengers' safety at risk and engage the integrity of the carriages. We present four potential applications for infrastructure monitoring.

Figure 1 - Left: Worldview 3 picture of Rio Stadium. Right: Zoom of the red zone. Credit: DigitalGlobe. The railway infrastructure is markedly visible, with noticeable details.

RIGHT-OF-WAY OCCUPATION

The right-of-way is a private land portion that belongs to the rail company. Nothing should be in this area.

Vegetation is the main intruder on the right-of-way. Its growth is especially dangerous when it enters the train’s gauge. An impact could cause major damages. Trees can also touch or batter catenaries, causing a slowdown in traffic for safety reasons. To manage the vegetation, SNCF buys satellite images once or twice a year to evaluate its nuisance. Pruning is planned accordingly, whether it is the responsibility of the railway group or the one of citizens living at the edge of the right-of-way.

Animals or human beings may also be found in the right-of-way. Sometimes, people even construct structures in this area. Except for entitled workers and their tools, this encroachment is undesirable. Hence, a regular monitoring is needed. With near-real-time satellite observation, it would be possible to detect trespassing and dangerous behaviours.

NATURAL DISASTERS AND THEIR IMPACT: PREDICTION AND DETECTION

In Europe, violent weather is limited to storms, heavy rains or strong winds. It has the consequence of flooding tracks, trees falling on them or tearing off catenaries, resulting in shutting down electrical power. In mountain areas, it can cause landslides and rocks on the tracks. The impact of violent weather has severe inconvenience but is rarely a deadly disaster.

Asia is harshly struck by natural disasters: typhoons, earthquakes, volcanic eruptions and their results. Damages to the infrastructure can hardly be prevented. However, being prepared would increase safety and the optimization of maintenance plans.

With satellite images it is possible to learn the features and precursory signs of previous disasters. Taking into account the land condition after the event would increase the reliability of the prediction. It would then be possible to better prepare for and answer to critical events. Traffic adaptation, substitution route, travel rescheduling, assets protection, rescue planning, etc. would strongly benefit from satellite constellation high frequency data.

OBSTACLES DETECTION

Obstacles on the railway almost always cause damages to the train as it is impossible to avoid them. In doing so, they engage passengers’ safety. It is a priority to be able to detect them as early as possible.

Obstacles may come from both natural disasters and the environment, which were covered in previous subsections. Additionally we can include railroad crossing monitoring. Every year in France, the average number of train-car collisions is a hundred, killing thirty people and seriously injuring fifteen. Even though accidents mainly occur because of human errors, there is a true added value in early detection of an obstructed crossing. Obstacles detection would merge the vehicle detection on-going works with the railway needs.

INFRASTRUCTURE CONDITION AND MAPPING

Very high resolution satellite images show lots of details in the observed scene. It is for instance possible to notice a broken portion of the rail or a damaged catenary pole. Thus it could be possible to evaluate the infrastructure condition using satellite images.

The mapping of the railway network is an essential part. It would give the precise location and geometry of the infrastructure, the details of the nearby lands, the altimetric measurement, i.e. all the information needed for a proper maintenance service. This map could also include the on-going and planned construction work. An interesting addition would be the positioning of the trains. To make the map complete, one could add the prediction of the weather and the assets available. This global tool, regrouping data from various sources, would drastically improve the management and maintenance of the railway assets and land.

This variety of applications implies different acquisition frequency requirements. For example the vegetation growth is slow and requires a once-a-year surveillance. On the other hand, the infrastructure is subject to rapid climate changes: damage could happen at any time. A shorter revisit time would better suits this need, especially after a disaster. Obstacles detection needs an even quicker data refreshment pace. Every application case must be individually addressed to evaluate the specificity of each and create a global railway surveillance tool.

5. ECOLOGICAL IMPACT

Over the years, many objects have been sent into space. At the moment, the LEO orbit is a place where are orbiting functional satellites, wrecked ones, remaining junks from various launches and debris. It is said that more than 29.000 objects bigger than 10cm are orbiting the planet (ESA 2013). Smaller ones are believed to be in the millions. Sixty years of satellite activities have made the LEO orbit a crowded place where it is difficult to find a safe orbit.

In recent years, satellite technology has become accessible. However for near-real-time observation with a proper spatial resolution and swath, the size of a constellation has to be substantial. Furthermore, due to reduced lifetime of LEO satellites, more frequent launches would be needed to maintain constellations working. It will induce more junk. This highlights two essential questions. *How to launch new satellite missions in a safe environment*? *How to build a technology that will not end as litter in space*? Concerning the first question, start-ups and government agencies' on-going works propose cleaning satellites to capture and destroy useless objects. The use of nets (CleanSpace One, Remove DEBRIS, OSCaR), magnets (Astroscale), laser (SHEN 2014) or robotic arms are considered and in the testing phase.

The ecological footprint of satellite missions was not taken into account until recently. There are different steps to monitor just to put the satellite in orbit, such as hardware construction, rocket launch and propulsion, etc. Once in space the satellite acquires data and sends it back to earth. The size of satellite images and quantity of data from a constellation requires important energy consumption for acquiring, storing and processing such enormous amounts of data. AI-based methods, which use high volumes of data, shall aim at reducing their ecological impact. It could focus on data aggregation, energy-efficient data acquisition techniques (WU 2016), deleting unimportant data, improving data transmission scheduling, using transfer leaning, etc.

In 2009, ESA conducted an internal study to evaluate the environmental impact of space activities. It resulted in a handbook containing guidelines on how to use Life Cycle Assessment (LCA) for space and ground segment (Figure 2). Along with this work, NASA is also working on making space launches more sustainable (NASA 2015). The institution successfully tested a new “green” fuel. It is supposed to be 50% more efficient than the current propellant (hydrazine) with low toxicity (for both the environment and the workers). This

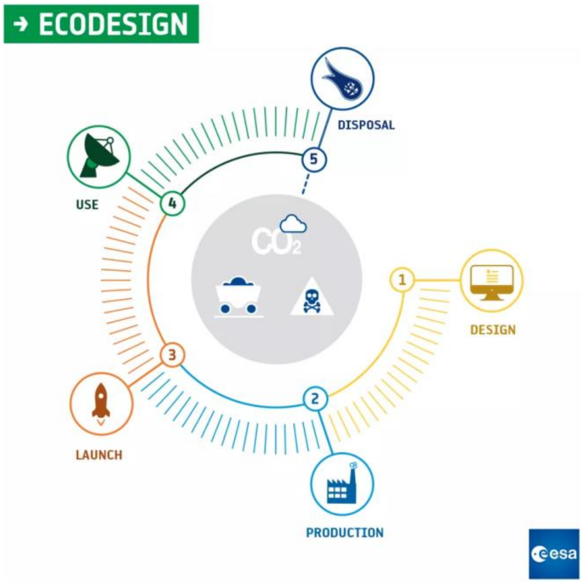

Figure 2 - EcoDesigning a space mission. Credit: ESA

propellant is also higher in density. Hence spacecraft could use less fuel for longer mission and more fuel could be stored in the same volume containers. The SatRevolution company is addressing the space pollution problem by designing satellites that would be automatically deorbited and vaporised into the atmosphere after three years.

High frequency imaging constellations are still an on-going research field. Therefore there is still time to improve their whole life cycle.

As a key player in low carbon mobility, SNCF must investigate the sustainability of the satellite monitoring solution. A complete comparison study with the LCA of terrestrial devices should be performed before taking a decision.

6. CONCLUSION

Microsatellite constellations are booming. To date, the author is aware of nine companies currently working on high frequency satellite imaging constellations. Together, they will be responsible for an additional two thousand satellites in the LEO orbit. The amounts of data they will produce will be considerable. Manual analysis is inconceivable. The rise of AI algorithms and their validation in other scientific domains offer new possibilities for fast and automated processing of large Earth Observation datasets.

This future high-frequency data will have a great potential for transportation, especially in the railway field. Depending on the refresh rates, surveillance applications such as trains positioning, infrastructure monitoring, natural disaster prediction and mapping could benefit from satellite images.

The ecological impact of a satellite's complete life cycle is not yet well known. This matter has to be addressed from the design phase to the disposal of the machine. Extensive studies have to be conducted before choosing this particular technology over another.

Overall, researches on high-frequency imaging constellations have highlighted new potential applications. Combined with high ground resolution and new machine learning algorithms, satellite images will contribute to develop smarter transportation systems.

7. REFERENCES

References from Journals:

L. ABRAHAM, M. SASIKUMAR 2014, *Vehicle Detection And Classification From High Resolution Satellite Images*, ISPRS Annals of Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume 2, Issue 1, pp.1-8

A. S. BELWARD, J. O. SKOIEN 2015, *Who launched what, when and why ; trends in global land-cover observation capacity from civilian earth observation satellites*, International Society for Photogrammetry and Remote Sensing, Journal of Photogrammetry and Remote Sensing, Volume 103, pp. 115-128

L. CAO, C. WANG, J. LI 2016, *Vehicle Detection From Highway Satellite Images Via Transfer Learning*, Information Science

L. CAO, F. LUO, L. CHEN, Y. SHENG, H. WANG, C. WANG, R. JI 2017, *Weakly supervised vehicle detection in satellite images via multi-instance discriminative learning*, Pattern Recognition, Volume 64, pp.417-424

L. CHANG, R. P. B. J. DOLLEVOET, R. F. HANSSEN 2014, *Railway Infrastructure Monitoring using Satellite Radar Data*, International Journal of Railway Technology, Volume 3. Issue 2, pp.79-91

L. CHANG, R. P. B. J. DOLLEVOET, R. F. HANSSEN 2016, *Nationwide Railway Monitoring Using Satellite SAR Interferometry*, IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, Volume 10 , Issue 2, pp. 596 - 604

G. GARG, A. KAUR 2016, *Study Of Various Vehicle Detection Techniques _ A Review*, International Journal of Advance Research, Ideas and Innovations in Technology, Volume 2, Issue 3, pp.1-5

S. J. GOETZ, R. K. WRIGHT, A. J. SMITH, E. ZINECKER, E. SCHAUB 2003, *IKONOS imagery for resource management: Tree cover, impervious surfaces, and riparian buffer analyses in the mid-Atlantic region*, Remote Sensing of Environment, Volume 88, Issues 1-2, pp. 195-208

M. KUBAT, R. C. HOLTE, S. MATWIN 1998, *Machine Learning for the Detection of Oil Spills in Satellite Radar Images*, Machine Learning, Volume 30, Issues 2-3, pp.195-215, Springer

Y. LI, C. TAO, Y.TAN, K. SHANG, J. TIAN 2016, *Unsupervised Multilayer Feature Learning for Satellite Image Scene Classification*, IEEE Geoscience and Remote Sensing Letters, Volume 13, Issue 2, pp.157-161

S. K SEELAN, S. LAGUETTE, G. M. CASADY, George A SEIELSTAD 2003, *Remote sensing applications for precision agriculture: A learning community approach*, Remote Sensing of Environment, Volume 88, Issues 1-2, pp. 157-169

S. SHEN, X. JIN 2014, *Cleaning space debris with a space-based laser system*, Chinese Journal of Aeronautics, Volume 27, Issue 4, pp.805-811

C. V. TAO, Y. HU & W. JIANG 2004, *Photogrammetric exploitation of IKONOS imagery for mapping applications*, International Journal of Remote Sensing, Volume.25, Issue.14, pp.2833-2853

M. WIELAND, M. PITTORE 2014, *Performance Evaluation of Machine Learning Algorithms for Urban Pattern Recognition from Multi-spectral Satellite Images*, Remote Sensing, Volume 6, Issue 4, pp. 2912-2939

J. WU, S. GUO, J. LI, D. ZENG 2016, *Big Data Meet Green Challenges: Greening Big Data*, IEEE Systems Journal, Volume: 10, Issue: 3, pp.873-887

X. YAO, J. HAN, G. CHENG, X. QIAN, L. GUO 2016, *Semantic Annotation of High-Resolution Satellite Images via Weakly Supervised Learning*, IEEE Transactions on Geoscience and Remote Sensing, Volume 54, Issue 6 , pp.3660-3671

References from Other Literature:

A. BRACHER, B. M. SINNHUBER 2009, *An Introduction to Remote Sensing*, summer class, Bremen University, Germany

NASA 2002, *First Picture from Explorer VI Satellite*. Archived from the original on 2019-07-30.

NASA 2015, *Green Propellant Infusion Mission Project*, NASAFacts

K. C. RUFFNER 1995, *CORONA: America's First Satellite Program*, Washington D.C.: Central Intelligence Agency, 360 pp.

References from Conference processing's:

X. CHEN, H. SUN, H. YANG, Z. ZHANG 2010, *Urban spatial growth analysis from satellite-derived imperviousness in an oasis city*, 2nd Conference on Environmental Science and Information Application Technology, IEEE

A. DIAF, K. BENHANIFIA, D. YOUSFI, H. BENYELLES 2009, *Use of the potential of satellite images in the detection of farmland mutation by urbanization*, International Conference on Advances in Computational Tools for Engineering Applications, IEEE

J. LUO, P. DU, S. ALIM, X. XIE, Z. XUE 2014, *Annual Landsat analysis of urban growth of Nanjing City from 1980 to 2013*, Third International Workshop on Earth Observation and Remote Sensing Applications (EORSA), IEEE

H. MA, N. LU, L. GE, Q. LI, X. YOU, X. LI 2013, *Automatic road damage detection using high-resolution satellite images and road maps*, International Geoscience and Remote Sensing Symposium – IGARSS, IEEE

L. XIE, L. WEI 2013, *Research on Vehicle Detection in High Resolution Satellite Images*, Fourth Global Congress on Intelligent systems, IEEE

L. XU, T. JUN, Y. XIANG, C. JIANJIE, G. LIQIAN 2012, *The rapid method for road extraction from high-resolution satellite images based on USM algorithm*, International Conference on Image Analysis and Signal Processing, IEEE

G. ZHOU, M. KAFATOS 2002, *Future Intelligent Earth Observing Satellites*, International Society for Photogrammetry and Remote Sensing, FIEOS Conference proceedings, Special session.

References from websites:

AXELSPACE, https://www.axelspace.com/en/axelglobe. Accessed on 2019-07-31.

K. BRABAW 2019, NASA's 'Green' Fuel Satellite Passes Its First Test, https://www.space.com. Accessed on 2019-08-21.

ESA 2013, *How many space debris objects are currently in orbit*, https://www.esa.int/Our_Activities/Space_Safety/Clean_Space/How_many_space_debris_objects_are_currently_in_orbit. Accessed on 2019-08-27.

M. STRAUSS 2017, *Flotilla of tiny satellites will photograph the entire Earth every day*, Science Magazine in Earth,Technology, www.sciencemag.org