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Control and Maintenance of Railways through Satellites. Is it possible?

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Abstract

The framework of this paper falls within the needs of optimization of the expenses in maintenance in railroads, contemplating the cost of the infrastructure from a life cycle approach.

In the last 25 years, there has been a strong investment in new high-speed railway infrastructures. After putting a new infrastructure into service, it is very important to avoid losses of the value of this asset by means of adequate maintenance actions. Given the economic situation of the last years, it is necessary to optimize the resources allocated to railway maintenance, with criteria of efficiency and austerity.

In this paper, new sources of information have been sought to determine the state of the infrastructures and their maintenance needs. It analyses the possibility of integrating aerospace knowledge to carry out these controls and monitoring tasks through satellites as a substitution of control and visual monitoring or, like the latest innovative proposals, using drones.

Within the capabilities of the satellites, a more detailed evaluation of those that could be useful for railway maintenance, such as satellites with capacity to measure soil moisture, to take high resolution images or to control the surface movements.

Throughout this paper, it is intended to make a comparison between the necessary measurement ranges in railway maintenance and the possibilities that give us the artificial satellites.

Keywords: maintenance; railways; satellites.

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1. Introduction and Objectives

The applications of the satellites have been developed in different fields, from applications in agriculture, for the control of the crops, through the maritime control of boats, allowing their constant location in zones of high danger, to the control of fires, droughts, flooding or the control of pollutants in the atmosphere.(Duncan, Prados, & Lamsal, 2014)

Within the field of engineering, different applications have been developed, such as the control of surface movements in tunnel covers or slope movements (Guzzetti, Cesare Mondini, & Manunta, 2012), or applications to improve the layout of roads (Copernicus, 2014), but the low resolutions available until relatively recently have prevented a greater contribution to this field.

With the development of satellites, obtaining resolutions lower than the meter, together with the development of image processing and the evolution of radar, this technology becomes an important field of research for the future.

This research includes the following tasks: to study new ways of optimising the conservation and maintenance of railway infrastructure using aerospace technology, more specifically via satellites. The main objective is to find a way of optimising resources for the conservation and maintenance of railways by using artificial satellites.

To this end, intermediate objectives are established that allow us to reach the main one. Firstly, it will be necessary to carry out a study of the current operation of railway maintenance, in order to establish railway's needs. Within the rail system, we focus on those parts that can be measured from satellites.

In addition, we seek a better understanding of the different types of existing satellites and the possible applications offered by each of them. In this way, the aim is to compare the maintenance needs with the possibilities offered by satellites in the control and maintenance of railway tracks to show future practical applications.

2. Methodology

In order to achieve the objectives set, an analysis of conventional railway maintenance will be carried out. Based on this analysis, the elements to be controlled and the measuring ranges used in maintenance operations are determined.

On the other hand, we study the different capacities offered by artificial satellites, establishing also the measuring ranges. Different visits have been made to expert aerospace centres based on the visualisation and control of satellite data in the Madrid sector (AirBus, European Space Agency ESA, academy), as well as interviews with experts and search for technical information in the aeronautical sector.

Finally, a comparison matrix is developed to determine which satellite technologies could be implemented.

3. Results

3.1 Railway maintenance

The standard UNE-EN 13306: 2011 defines maintenance as the combination of all technical, administrative and management actions, during the life cycle of an element, intended to preserve or return it to a state in which it can perform the function required.

In any element, we can distinguish two main types of maintenance, according to the occurrence of the failure: preventive maintenance, when maintenance aims to avoid failure, and corrective maintenance, which is done when the failure of the element has already occurred.

Preventive maintenance operations aim to minimize the likelihood of a failure in the elements, due to the associated operating risks and the higher cost that the corrective maintenance associated with the failure entails. Within preventive maintenance, we can distinguish the predetermined maintenance (which is performed according to established time intervals or operating units), and maintenance based on the condition, where the condition of the element is monitored or inspected to determine the actions to be undertaken.

The railways are composed of a multitude of elements, with different modes of degradation and maintenance operations. To determine how we can facilitate or improve maintenance through the use of satellites, it is necessary to analyse the operations necessary to know the state of the different subsystems. These surveillance operations can be done both on foot and on the road on railway vehicles, whether these are specific to these tasks (or other maintenance), commercial vehicles. All these operations have in common that they are carried out in the own infrastructure. Surveillance tasks that can be remotely controlled (such as knowing the occupation of a track circuit) are not the subject of the present study.

Each of the subsystems that compose the railway system is analysed, in order to ascertain the operations that can be carried out by satellites. In the infrastructure subsystem1, we distinguish the track from the platform. The first includes the following elements: rails, sleepers, fastenings, track foundation (ballast and sub-ballast), or concrete slabs, as well as other devices that are placed on them: diversions, escapes, sleepers, expansion devices, etc. In the second, we include the different types of civil works that we find in a railway infrastructure: natural platform (embankments, trenches, form layer, etc.) and artificial platform (tunnels and viaducts), as well as their drainage systems. The surveillance and inspection operations in this subsystem focus on the following:

In the case of the track, it is interesting to know both the state of the elements and the geometric quality of the elements.

- In the case of the condition of the elements, the main operations are the control of the rails (wear and internal state by ultrasonic auscultation), as well as control of the condition of the materials (ballast, sleepers, joints, fastenings, welds, Track, etc.).
- In relation to the geometric quality, it is determined by five parameters: leveling, longitudinal and transverse, alignment, gauge and warpage (UNE-EN 13.848-1: 2004). Measurement of geometric quality is a way of measuring the state of the set, as it is influenced by the state of the track elements themselves and by the underlying support structures (track foundation and platform).

Regarding the platform, monitoring operations depend on the type of element. In embankments and trenches, movements are sought, paying special attention to the blocks that can be detached and fall on the track in excavation zones.

In relation to the condition of the elements, the following specific aspects of certain elements should be indicated:

- Ballast: it is necessary to verify the possible contamination of the ballast. The contamination is the ballast dust that stems from its crushing, and which is characterized by the whitish colour that appears in the surface of the ballast layer. Other parameters to check are the dimensions of the layer, the slopes, the ballast shoulder, the amount of existing ballast and the presence of vegetation.
- Sleepers: the maintenance operations consist on checking that are no cracks, and that no

voids exist under the sleepers, which could compromise the transmission of the load to the ballast.

- Fastenings: during maintenance operations, it must be checked that they are correctly tightened, that they are correctly positioned and that they have not been removed.
- Bridges and tunnels: check the structural condition, verifying that there are no cracks in walls, boards, etc.
- Drainage systems: cleanliness of pipes, taps, culverts, siphons and gutters and the presence of herbs will be monitored.
- Surroundings: there mustn't be any obstacles that could obstruct access to the road by maintenance personnel, and that the perimeter protections have not undergone any alteration.

The operations to determine the status of this subsystem are as follows:

- Auscultation: measurement of parameters of the track and its elements. We distinguish several types:
  - Geometric auscultation: it measures the parameters of geometric quality previously mentioned. For this purpose, a geometric control car is used, of which there are several examples depending on the network. In addition to the control performed by this type of trains, the geometrical control of the track can be performed by manual or topographic methods or even using the records of the batting machines during their operation. o Dynamic auscultation: it measures and records accelerations in bogies, journal box and vehicle box. Each of the accelerations measured by the auscultation train reflects different path defects. They also determine the comfort of the traveller.
  - Ultrasonic auscultation of lanes: Ultrasonic auscultation allows the detection of internal rail defects. This operation is not the object of this work, since this type of defects is not observable by means of satellites.

• Walking routes/ train rides: routes and rides have a fundamental role in preventive maintenance activities, since they are intended to verify the elements whose parameters are not controllable through the different types of auscultation previously described. They can be on foot (routes) or inside the train (rides): the former are more exhaustive, but much slower; the second are faster, and allow to evaluate the dynamic behaviour of the trains. The periodicity for the realization of both types is marked by the infrastructure manager.

In the energy subsystem, the determination of the state of the mechanical elements (posts, contact wires, supports, etc.) is done by the use of special vehicles. The parameters that are measured are the geometric quality of the catenary, and the wear of the wire. The status of the catenary posts can be determined by means of train rides.

In the control, command and signalling subsystem, most of the elements are remotely controllable (such as signal status). For this reason, most of the maintenance operations are either periodic, or are based on the warnings that the different systems give about their operation. Train rides may be used to determine the condition of cable conducts (open caps or misalignment), or the condition of signal posts.

3.2 Artificial Satellites

There are different classifications of artificial satellites. Depending on their use, these include meteorological satellites, military satellites, telecommunications satellites and so-called earth observation satellites. Within the terrestrial observation satellites, we can distinguish between optical satellites and satellites of image capture with synthetic aperture radar technology.

- Optical satellites are characterized by their high spatial resolution and the range of the electromagnetic spectrum they capture, being influenced by the presence of clouds in the imaging.
- Satellites with synthetic aperture radar technology are not conditioned by the presence of clouds, since their operation is based on the emission of electromagnetic pulses and the capture of the rebound.

Both images of optical satellites and those obtained by radar are subjected to rectification processes such as orthorectification or interferometry.

In addition to classification based on the function they perform, another differentiation in the typology of satellites can be made depending on their orbit. The orbit of a satellite is characterized, firstly, by the centre of rotation (geocentric or heliocentric). In the geocentric satellites, the orbit is classified according to the height, where HEO (High Earth Orbit) exist, above the 35,786 km; MEO, between 20,000 and 35,786 km; and LEO, below 20,000 km (Gaetano Hadad & Blanco Arias, 2009). The latter usually get better resolutions, so they will be those studied in the present work. LEO satellites are divided into orbits synchronized with the Sun, or polar.

The type of orbit and its altitude will characterize the period of passage through the same point, and therefore the frequency of capture of images at the same point that they will have. There is a large amount of satellite data applicable to different fields, given the large amount of information they generate, although there is still some difficulty in interpreting and processing such information. Some of the possible applications are described below.

One of the areas where significant progress has been made is the control of pollutants produced in industrial sectors, allowing the monitoring of columns of contaminants produced in farms and fires. In addition, by observing the concentration of different gases, it is possible to support air quality prediction models, including the generation of new models, and to estimate anthropogenic emissions, thanks to the ability of these satellites to measure the number of molecules of certain gases, like NOx, SO2 in scarce emissions and NOx, CO and CH4 in larger emissions, existing between the Earth's surface and the satellite. These measurements allow the creation of maps of temporal evolutions of emissions, from daily to annual scales, and the monitoring of concentrations (Duncan et al., 2014).

To develop these tasks, agencies like NASA have developed satellites such as Terra, Aura or GOES. However, this use has certain limitations, such as the lack of information regarding the vertical distribution and composition of these columns. However, they do not seem to be applicable in our field, since there are no large concentrations of pollutants in the railway system.

The use of satellites to control soil moisture is mainly focused on improving weather forecasts, drought control and the possibility of associated fires, predicting possible floods and improving water use on farms (NASA, 2004b). This satellite typology uses synthetic aperture radar (SAR) systems for the detection of moisture from the surface layers of the earth. SARs are so-called active sensors, which record high spatial resolution images (Sillerico, Marchamalo, Rejas, & Martínez, 2010). These radars measure the electromagnetic radiation of any body that is at a given temperature (Universidad Politécnica de Cataluña, 2009). This radiation will depend on the composition of the soil, so applied techniques of interferometry can obtain the soil moisture and salinity of the oceans. SAR interferometry is an applicable technique in different areas. It involves the use of a satellite to record two or more images of the same area at different time points. When comparing the different images, it is possible to detect any changes that may have occurred in that period of time (AIRBUS, 2012).The most important satellites in this field are the SMAP of NASA and the SMOS of the ESA. They differ from satellites with radar technology because of their ability to take pictures in different spectra.

Flexibilization of regulations that prevented high resolution images from space has allowed resolutions of up to 0.30 m to be reached in panchromatic mode (Satellite Imaging Corporation, 2015), characterized by an observation made in a single spectral band located in the visible part of the spectrum electromagnetic (Spot Image, 2005).

The applications of the high resolution images in the railway maintenance can vary, from the control of the existing vegetation near the track, until the observation of changes of colour in the infrastructure that can indicate different problems.

Within this field there is a very wide offer, so that only cite some with different resolutions and operated by different companies:

- WorldView-3: resolution of 0.30 m.
- WorldView-2: resolution 0.46 m.
- Pleiades: 0.50 m resolution.
- Spot 6/7: resolution of 1,50 m.
- KazEOSat-1: resolution of 1.00 m.
- Kompsat-3: resolution of 0.70 m.
- RapidEye: resolution of 5m.

Satellites capable of detecting surface movements on slopes are based on the same technologies as soil moisture detection, i.e. SAR satellites, differing from these at the wavelength at which they emit. While satellites whose objective is to measure soil moisture emit in wavelengths around 21 cm and a frequency of 1.4 GHz, band L of the electromagnetic spectrum, the satellites used in the detection of surface movements work in variable wavelengths depending on the type of terrain and in the environment of 3.1 cm and 9.6 GHz (c and x bands of the electromagnetic spectrum).

From the techniques of interferometry, distance data are obtained between the satellite and the terrain surface, calculated by measuring time and time lags. This technique, also known as InSAR, of combination of 2 interferometric passages allows to measure phase differences in two satellite steps in the same zone. These differences can be due to the different position between the two satellite trajectories or because of a displacement of the observed area, so this technique allows the detection of movements and deformations of the Earth's surface. The signal received by the sensor is influenced by parameters such as atmosphere and surface movement (Sillerico, Marchamalo, Rejas, & Martínez, 2010).

Radar images are black and white, although colour images can be produced by combining 3 independent images of different dates, forming a composite image (European Space Agency, 2010).

From the InSAR technology, the differential SAR or D-InSAR interferometry is generated, which allows the generation of maps of the terrain displacement, from “n” steps of the satellite through the same zone. For the processing D-InSAR different techniques already exist. The most used is to obtain displacements from the areas away from the study area, which are assumed to be free of movement and with constant geometry. The DINSAR technique allows to eliminate some of the parameters that influenced INSAR interfeormetry (Sillerico, Marchamalo, Rejas, & Martínez, 2010).

The resolution of this type of images depends on the size of the images taken, varying this in each one of the satellites. Some of the satellites available today are:

1. Terrasar-X: its resolution in the X and Y planes vary between 0.25 m and 3 m, while their accuracy in the measurement of subsidence can reach 3.1 mm.

2. CosmoSkyMed: constellation formed by 4 satellites, located in synchronous orbits to the sun. Its resolution in the x-y plane varies between 1 and 5 m and its accuracy in the z-axis is around cm (Italian Space Agency, 2016).
3. RadarSat-2: Its spatial resolution on the earth's surface varies between 1 and 5 m depending on the image size captured, while the accuracy that can be achieved in the measurement of subsidence is 5.6 mm (Canadian Space Agency , 2015).

3.3 Feasibility of using satellites in railway maintenance

In order to study the usability of satellites in maintenance, a comparison has been made of the measurement ranges of each of the satellite capacities with the measurement ranges used in railway maintenance.

- **High resolution images:**

High-resolution images can be used to observe the variation of distances. For this it is necessary to take into account the highest resolution available in the market today, 25 cm in the horizontal plane, reachable only by the Worldview-3 satellite. This factor immediately discards the possibility of measuring path quality parameters located in millimetric ranges. In addition, it discards the defects of cracks present in sleepers or sleepers, nor the surface defects existing in the rails. Another element that could not be controlled by the use of satellite images are the fastenings between rails and sleepers, since their small size discards this possibility. However, we could control the ballast shoulder, distance between the lane and the beginning of the bank slope, which can vary between 90 and 110 cm.

On the other hand, high resolution images allow us to observe changes in colour between each satellite pass. This variation of colour can give us very useful information for the control of different elements:

- Emergence of vegetation in undesirable areas.
- Detection of areas of surface moisture where it would not be expected, which may reflect poor drainage or obstruction of gutters.
- Control of the existence of fauna or burrows that can deteriorate or weaken the embankments of the infrastructure.
- Contamination of the ballast, characterized by a whitish colour produced by the elevation of the fines of the ballast itself to the surface.
- Existence of obstacles in the access roads.
- Fence perimeter elements and fallen noise attenuation.
- Signalling vertical elements and fallen catenary posts.
- Slopes landslides and landslides.
- Existence of objects in the drainage elements such as ditches or pipes.

- **Humidity:**

The use of satellites such as SMOS or SMAP in the detection of surface soil moisture in rail maintenance has been ruled out due to the spatial resolution of these systems, which exceeds 10 km, and prevents the measurement of problems in linear elements such as Drainage of railway systems. However, it is important to highlight the numerous applications that these satellites could have if they had their spatial resolution improved.

- **Contamination:**

As mentioned in previous chapters, the application of satellites used in pollution control in industrial or urban areas is not applicable to railway systems, since there are no large concentrations.

- **Control of surface movements:**

Satellites studied reach precisions below the centimetre in the vertical axis, making possible the monitoring of superficial movements in earthworks. This control in traditional maintenance is done by sending surveyors to areas where there have already been appreciable movements by the human eye. This way of operating has a high cost and sometimes the control comes too late causing great deterioration in the road.

4. Conclusions

There is a need to find alternative cost-saving alternatives to traditional maintenance, which uses sometimes expensive methods, such as the use of surveyors and pedestrians. They also cannot detect certain deficiencies in the railway infrastructure.

The development of aerospace technology, and specifically artificial satellites, introduces the possibility of an improvement in the control of different elements of the railway platform. These systems allow us to obtain resolutions of up to 0.25 meters, in the case of optical satellites, which we can consider sufficient for the measurement of some important distances in the maintenance like the shoulder of ballast The mentioned resolution together with the possibility of obtaining the colour of each pixel of the image allows the detection of the existence of obstacles or fallen elements in the surroundings of the railway platform, in the elements of superficial drainage or in the own railway infrastructure.

The presence of damp areas that indicate a malfunction of the drainage systems and the accumulation of water in undesirable places can be detected, by means of the control of the colour changes, thus facilitating the improvement in the prevention of possible problems in these systems. In addition, this capacity allows us to perform a better control of the existing vegetation, optimizing the planning of the works of weeding and irrigation of herbicides, and with that of the resources available for these works. Another important application of highresolution colour imaging is the control of the existence of wildlife, such as rabbits, that can deteriorate the state of the embankments, leading to landslides.

On the other hand, satellites based on radar technology offer the ability to measure vertical subcentimetric movements, giving the possibility of control of slopes and embankments in problem areas.

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