Prospects of High Technologies in the Remote Diagnosis of the Track

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Abstract: The article assesses trends of development of devices for control and diagnostics of railway tracks, highlights the growing importance of advanced technologies that make use of more sophisticated methods of remote monitoring of the technical condition and ensure safe operation of railroad bed. In particular, the authors analyze in detail the results of their own developments, with an emphasis on options for optical control with the use of aircraft and video recording, significantly expanding the possibilities of monitoring and quality of observations, and at the same time forecast (considering experimental data and economic factors) promising areas of engineering research.

Keywords: railway, track monitoring, remote diagnostics, aerial photography, optical sensors, polarization of reflected light, infrared technology, satellite communications.

Introduction

As we know, a number of immutable factors (primarily, the need to increase operating speeds on the railways, to achieve additional traffic safety guarantees with account for not only "uncreated" man-made threats) forces constantly to look for more efficient and reliable control devices in all respects of tracking of technical condition of the track, conditions of the right-of-way.

There is a fairly definite picture of vectors of engineering research where high-tech solutions and projects claim to dominate. Some of them are implemented; others are likely to have different degrees of readiness and experimental verification.

Vector disposition

The general trend in the situation, from the very origins guided by enforcement promises, have remained the same for nearly two centuries: live visual inspection with direct participation of a person (track patrolman), as soon as the slightest opportunity appeared, was immediately supplemented by independent technical expertise, objective data of instruments and measurement, engineering analysis. Moreover, with the increasing complexity of track measuring equipment which was put on the track carts, placed in special cars, troubleshooting gradually transformed from a contact to a non-contact one, using as instruments the most promising means of detection of defects, technological risks, direct threats to traffic safety.

If we take into account methods of troubleshooting of the state of the track (railway complex elements), which have become known in recent years, then used and proposed methods can be grouped as follows.

1. **Mechanical methods**. These include, for example, a system of rail structures diagnostics, created on the basis of micromechanical sensor elements [11]; a technique to assess dynamic effects of the vehicle on the track, built on the spectral analysis of the responses received to the shock pulse and in-

volving monitoring with the use of vibration sensors that convert mechanical vibrations recorded by them into electric signal [18, 14]; a method of continuous change of the vertical forces in the contact area of wheel and rail with dynamometric wheel sets, allowing to fix deformation of a spoke or a disc, and thus the state of individual sections of the track [16].

2. **Ultrasonic methods**. An example where by multiple reflection of the ultrasonic pulse from the boundaries of the control object by SAFT method imaging of defects in rail base blades is provided is shown in [2]; similar opportunities for ultrasonic inspection are provided by examination of the surface of the rail in order to detect appearance of cracks and fractures during tracking the dynamics of the defect in order to prevent accidents on the road [e.g. 9].

3. **Signal- reproducing means**. Highlighting of that category by us is based on the fact that in the process of troubleshooting new narrowly functional, but very useful clips and repeaters of controlled data are offered, including acceleration sensors used for inertial measurement of track irregularities [3], as well as angular movement sensors used for monitoring the state of the rail track [7].

4. **Methods for diagnostics of ballast and subgrade**. In particular, this category refers to registration of deformability degree of under-rail and under-sleeper grounds during load tests, which are carried out by mobile diagnostic complexes [1]; to monitoring of the roadbed and track superstructure on the basis of a three-level control system [17]; to analysis of the ballast layer with undersurface radars [10]; to organization of permanent automated posts for mode observations of deformations of high railway slopes using deep groundwater frames based on inclinometers PIN [15].

5. **Methods of optical control**, that fix most clearly predominant trend towards the development of remote diagnostics of the railway track. In that case, the choice of technological combinations depends on methods of video recording of a controlled object and on capabilities of signal- transforming systems, as well as on equipment carriers, monitoring means. The examples are: a) use of the effect of polarization during reflection of light in the visible range of the electromagnetic radiation from the surface of the rail head and further algorithmic processing of images, received from cameras [12, 4]; b) use of remotely piloted aircrafts (RPA) or other types of air vehicles (including helicopters [6]) to conduct surveillance in a flexible mode of diagnostic problems (in particular, we can cite an option of RPA with scanners, performing multispectral imagery in visible and infrared ranges of the electromagnetic spectrum; while devices of GPS / GLONASS system can be used as a surveying system, orienting to reflect on the map local objects and identifying marks on the track and in the right-of-way [13, 8]).

Research intensity in each case is provided, of course, by its own means and methodological approaches, but it is important to emphasize the desire to go beyond the usual technique, to denote approaching to the current level of practical requirements and technical process. From this point of view, in our opinion, the experience of participating in the development of two above mentioned types of optical control is illustrative.

Approaches to the method implementation

In a professional community of transport specialists each discussion on any scientific problem has a subtext of topics of risks, threats to safety on the roads. It is also always current for railways. Therefore, the development of improved technical means of diagnosis of the railway track, including those that allow installation on aircrafts, remains a need, first of all determined by this reason.

With regard to the same demand we consider, of course, a possibility of using fluorescent polarization effect of reflected light from the metal surface of the rail head for detecting traditional defects of rails, fasteners, sleepers, monitoring ballast layer condition. Justified by that basis, a non-contact method had passed through its own specific stages of development and experimental verification before it could qualify for some kind of continuation.

Upon reflection of the radiation of natural daylight, which is by its very nature non-polarized, from the boundary between two media (air-metal) its partial polarization occurs, which depends on the one hand, on the viewing angle, and on the other hand – on the optical properties of the contacting media. The change of polarization characteristics of the reflected light carries information about the parameters of the surface. By tracking those changes, it is possible to determine the properties of the surface layer of metal. In our case, the objects of study are the rail heads, and as for normal operation they should have almost perfectly flat upper surface, all defects and foreign objects, different in polarization characteristics of the smooth track surface will show an increased contrast in the images after processing by the method described below. Due to significant loads generated during the passage of trains, various defects appear on the surface of the rail heads. Consequently, the rays reflected from the element areas, receive different polarization characteristics, thus allowing to detect local defects (chips, cracks, rail corrugation and so on).

In natural light variation of the electromagnetic field vector is chaotic, because it is a set of many incoherent components. In this case, all directions of the electric field are equally probable. Such light is called non-polarized. If any direction of the vector is preferred then such a wave is recognized partially polarized.

There are different methods used for description of polarized light (Poincare sphere, Stokes vector, Jones vector, the quantum mechanical image). We have chosen the Stokes vector, as it makes it easier to analyze the passage of rays of light through optical systems.

Stokes vector is a set of four values, called Stokes parameters that characterize intensity and polarization of light. Those parameters have the dimension of intensity; each of them corresponds not to the instantaneous intensity, but to the intensity, which is average in time required for measurement. Four parameters are the column vector

$$\begin{bmatrix} I \\ Q \\ U \\ V \end{bmatrix}$$

The first parameter I is intensity. Parameters Q, U and V are consequently parameter of preferential horizontal polarization, parameter of preferential polarization at the angle of 45 ° and parameter of preferential right-circular polarization. When a parameter has a negative value, it means that polarization of orthogonal shape is preferential.

The proposed method consists of recording the reflected light from the surface of the rails using photodetector equipped with a polarizing filter (like SLR camera). The railway track is processed fragment-wise, the size of each fragment is determined by the size of the matrix of the recording device, lens focal length and the distance from which the survey is conducted.

To establish relations between the polarization characteristics of the electromagnetic wave before and after the filter, Mueller method is used. It is a matrix description of the interaction of the light beam and of an optical device through which light passes, and helps to calculate the result of such a process.

Since the removal or installation of the filter could cause displacement of the camera and violate the framing, as well as to improve the accuracy of the measurements, an improved method proposed in [5] is used, according to which for each part of the track a series of shots was made using different orientation of the filter.

It should be noted, however, that any spatial variations in the values of any of the Stokes parameters indicate as far as problems of shooting in the area of rail track are concerned, the presence of a surface feature of the rail, which could potentially be a defect.

Simplified, see their technical essence, experiments at the site of October Railway at Krestovsky Bridge in Moscow have shown a promising way to visualize defects using the effect of polarization of the reflected light and optical control means.

ADVANTAGES OF AIR DIAGNOSTICS

The use of aerial reconnaissance methods to diagnose the state of railway tracks is not a new idea [see.

e.g., 6], although a restraining motive, which is present here, is quite understandable. Introduction of aerial photography on a regular basis is still very expensive in terms of conventional piloted aerial vehicles, airplanes and helicopters, their ties with airbases, maintenance, accounting for takeoffs and landings.

A possible alternative is a RPA, mentioned above within the fifth classification group (methods of optical control), which stands for remotely-piloted vehicle with scanners on board. Army prototypes (USA, Israel) have proven their effectiveness, and an increasing interest to them emerges in Russia, too.

The main advantages of RPA for diagnostics of railway tracks are:

- High efficiency of use, ability to achieve a given stretch of track in a relatively short time, because the speed of RPA on the route can reach 200-250 km/h or more;
- Relatively low cost of operation of RPA as compared to other types of aircrafts, helicopters and airplanes;
- Use of RPA does not require intervals in timetable of trains, which are inevitable when using track-measuring cars;
- Route of RPA may be adjusted in accordance with the information received during flight and that route can deviate from the axis of the track at a considerable distance;
- Control of RPA in flight if communication with them is conducted through satellite channels or specially designed fiber optic lines running along the track (it is possible to use another RPA as a booster converter) can be performed centrally from a single command post;
- Presence of infrared technology on board gives a possibility to monitor the state of electrified railways, identifying certain areas of high heating of electrical circuits due to bad contacts, as well as to remotely monitor transformer houses and other equipment;
- Infrared sensors allow monitoring twenty-four-hour a day without additional lighting;
- System based on RPA can be a supplement to existing and planned protection systems, including security systems switching on CCTV cameras.

The use of RPA will help to expand the search area and assess operational situation when alarm signals are received from other sources.

Note, however, that engineering of such an expensive system to solve specific tasks may not be appropriate. From this point of view other tasks should be anticipated, in addition to those, which regularly can be met on the railway. The first is the observation of a possible crash site of trains, damage assessment and management of operations aimed at liquidation of consequences; then there is a task of regular fly-by of railways to assess the track state in order to ensure safe traffic.

Many of those ideas were taken into account during implementation of the project, carried out with the support of Russian Foundation for Basic Research and JSC "Russian Railways" (grant №11-07-13112-ofi-m-2011-RR). It was called "The use of RPA to obtain images of railways and the right-of-way in order to ensure traffic safety and prevent acts of terrorism" and provided an ostensible rationale for the very possibility of inspection from the air by means of optical imaging sensors, including multi-zone ones. And the threat detection can be carried out automatically, using mathematical methods of pattern recognition, as well as in "live" mode by a human operator.

Demonstrated approach takes into account the need for the ability to see the heterogeneity of the environment (nature of the violations of the ground surface, the color of vegetation or snow, etc.), dynamics of weather conditions, illumination of controlled areas (especially in the presence of clouds, sunshine, provoking the formation of harsh shadows ,contrasting backgrounds). Neutralization of some negative related phenomena, especially at dusk and at night, does not rule out the involvement of special electro-optical devices: TV cameras, capable of working in low illumination, and infrared devices.

Another possibility is the use of RPA using operational information for continuous observation of a designated section of the route in the loitering mode. Under this option it is possible to track an immediate moment of preparation of an act of unlawful interference into rail transport operation and to prevent the consequences of the derailment. To do this, images obtained in real time are to be forwarded to a central server, to be processed there, and at the moment of detection of moving objects on the tracks immediate communication with the security agencies is provided to take measures to counter the threat.

To solve the problem, it is possible to optimally choose a type of sensor that records the image. In good light conditions, it is possible to use a video camera, a high-speed optical camera or scanner with a line of sensors. It should be borne in mind that a video camera allows to get more frames per second than a photo camera. However, the photo camera produces an image with better resolution; its matrix has more points. As for a linear matrix scanner for image storage, it will need significantly less memory, because in this case there will be no duplication, when the same fragment of the railroad tracks is present on multiple frames. Another situation is inevitable: the image quality depends on the speed of flight of the equipment carriers.

To conduct aerial photography of railway tracks in winter at the experimental ring in Scherbinka, Moscow region, a remotely piloted aircraft of a helicopter type of the video studio DT group was used. The selection of a helicopter-type RPA was justified by its better handling in tight spaces and by significantly lower operating costs.

Aircraft RPA, having a much greater range and flight time, requires a developed ground infrastructure (devices of takeoff and landing, maintenance facilities, etc.) and numerous personnel to operate them. This type of devices is available only to entities (public and private) with significant resources. In addition, in Russia there is now no legislative framework governing the operation and the permission of such aerial vehicles for flights.

Helicopter aerial vehicle of multi-rotor type – multicopter, used for shooting, allows to receive bird's eye panorama photos and videos of good quality. Aerial photography may relate to natural sites, monuments, documentary scenes, music videos, festive events, sporting events and many other things. The use of this type of shooting during the research work was, apparently, the first experience in the practice of DT group, as well as any other contractors of such orders.

Control of the movement of RPA was carried out through radio channel. To get images an aircraft was fitted with a camera Canon EOS 5D Mark II, which provides a remote control of the gate by a separate desk and simultaneous transmission of signals through radio channel. The camera was mounted on gimbal suspension, from where picture was continuously transmitted to the screen of the control unit. In that case, the operator could focus the camera at the subject.

Power supply of electric engines of helicopters was carried out by storage batteries. Depending on the load the device was able to continuously stay aloft for up to fifteen minutes and to gain a height of over 100 meters. Preparations for the shooting took less than 30 minutes.

The use of RPA of a helicopter type is a temporary measure. This type of device fully satisfies the requirements of experimental works as a technology demonstrator. For the monitoring system of railways RPA of an aircraft type are more preferable, as having much greater flying range and time of staying aloft.

Accumulation of arguments and forecast

A changing global environment, entry into the era of global electronic networks, nanotechnologies and nanomaterials, respectively change evaluation criteria of approaches, in force hitherto, to control of condition and safety of the railways. Risks, losses, economic benefits get a new price, and therefore the things that only recently seemed too expensive and low efficient, now emerge in a different coordinate system, have qualitatively different projections into the future. And it is from this angle that it is necessary to assess the prospects for use of remote diagnostics, suggesting their further development and reasonable claim to be promising ones.

It is important to emphasize, first of all, that certain priorities of remote (including air) diagnosis are not opposed to any traditional "terrestrial" methods of tracking of technical conditions of an operated railway lines and under-rail, under-sleeper grounds. In varying degrees, the collection of such information is equidirectional, is a controlling process, which is complex in its aims, while none of the links can be taken out of the overall circuit. It is an axiom, which is clear for everybody.

The second fundamental point for the analyst: by isolating the interests of optical control and giving a special importance to them, it is impossible to be unaware of the need to build arguments for its priorities and, therefore, a critical interpretation of the results of experimental works, experimental check of ideas, offered by scientists and researchers, and of innovative solutions, should prevail. Designing of a trend is a considerable step in order to achieve at the end reliable, argued outcome.

In the context of existing materials we can confidently say that there is a rational and justifiable compatibility of not only contact and contactless diagnostics of the track, but already of long range diagnostics as well which is carried out at considerable distance from the earth's surface with the help of specially designed aircrafts and optical electronic monitoring devices.

Experimental data accumulated by our experts (in particular, at the facilities of October Railway, the experimental railway ring in Shcherbinka, Moscow region), as well as the views of numerous aerial photographs support this theses. Most often, pictures were taken in a densely populated area, which is typical for Western Europe and North America, and therefore it is certainly difficult to determine areas of risk or to assess the dynamics of accidents. However, there is an additional argument with regard to the Russian practice. After all, especially in the eastern part of the country railways are located mostly in uninhabited and inaccessible areas, and therefore, the use of RPA there is very productive and desirable considering many criteria, including purely economic ones.

Conclusion

Arguments, earlier put forward by researchers [8], and conclusions, summarized with their account enable to select multiple areas that could become a reference for RPA, tailored to remote diagnosis of the track and its safety.

It is necessary to use more purposefully the fact that operating costs of remotely piloted aircrafts are lower than costs of conventional aerial vehicles (airplanes, helicopters).

Railway-owned communication lines (they are laid along the rails) should be adapted for the needs of the flight control and receipt of information from RPA that will give additional savings for organization of monitoring control.

It is advisable to integrate aerial remote diagnostics to the relevant structures of railway companies, providing a certain cooperation (again, in order to reduce total costs) with the manufacturers and operators of RPA of this type.

In view of the emergence of optics, sensors, devices of a new generation, of increasingly sophisticated electronic means of communication and data processing there is a need for comprehensive approach to the design of models of remote monitoring of the technical condition of the railroad bed and safety of right-of-way, in view of achieving relevant goals and quality of diagnosis.

If high technologies will be fully in-demand at all levels of the system, being built in this way, its efficiency is not long in coming. In the meantime, the innovative research needs more coordination and joint efforts.

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