Archives of
Transport System
Telematics

Volume 11
Issue 2
May 2018

Inspection of the Railway Infrastructure with the Use of Unmanned Aerial Vehicles

A. KOCHAN, P. RUTKOWSKA, M. WÓJCIK
WARSAW UNIVERSITY OF TECHNOLOGY, Faculty of Transport, Ośrodek Certyfikacji Transportu, Koszykowa 75, 00-662 Warsaw, Poland
EMAIL: ako@wt.pw.edu.pl

ABSTRACT
The Transport Certification Centre at the Faculty of Transportation of the Warsaw University of Technology launched a research and development project under the name "Dron-monitor", which aimed to perform stocktaking and examine the technical condition of the railway infrastructure using unmanned aerial vehicles UAV. The assumption of the project was to create digital documentation of the railway infrastructure, which will enable an objective and impartial assessment of the infrastructure elements. The article presents the results of the conducted project and displays the considerations regarding the suitability of the applied method for the needs of conducting stocktaking and testing the technical condition of the railway infrastructure with the use of UAV.

KEYWORDS: railway infrastructure, unmanned aerial vehicles UAV

1. Introduction

On December 30, 2016, the Act from November 16, 2016 amending the Rail Transport Act and some other acts entered into force.

According to this amendment, railway sidings will become the part of the railway infrastructure, which will make infrastructure managers and sidings users obliged to provide data on their infrastructure to the national infrastructure register supervised by the Office of. Rail Transport. Those elements of infrastructure include:

- railway tracks, including turnouts and crossings of tracks, rails, nursery rails, steering wheels, fenders, guides, crossovers, crossings and other elements of turnouts, railway sleepers and attachments, small elements of the railway surface, ballast,
- subgrade, in embankments and trenches, drainage channels and ditches, curtain walls, vegetation planted to protect slopes,
- engineering structures: bridges, viaducts, culverts and other bridge constructions, tunnels, passages above and below the tracks, retaining walls and embankment reinforcements;
- railway traffic control devices,
- rail and road crossings and rail level transitions, including devices and systems to ensure road and pedestrian safety,
- lighting systems for rail and safety purposes,
- devices for the need of traction power supply: substations, power cables, traction network together with supporting structures.

In relation to the above, railway sidings managers should express a demand for an inventory service of the infrastructure being managed. Inventory should be understood as checking:

- compliance of the inventory status (specified in the siding documentation such as siding regulations, schematic plan, etc.) with the real state,
- checking the technical condition of the elements listed in the Act in terms of safety.

Transport Certification Centre observing this phenomenon, launched an internal project "Dron-monitor" aimed at assessing the possibility of using unmanned aerial vehicles (UAV) to automate the inspection of railway infrastructure facilities and support inventory actions.

Currently, the unmanned aircraft, often called "drones" should be seen as devices used, among other uses, to automate tasks related to the monitoring of large infrastructural objects. Such facilities include railway lines and sidings. Their linear character and area coverage creates a lot of problems when implementing their supervision by railway security personnel. That is why searching for automation methods for this process is desired.

The assumption of the "Dron-monitor" project was to support the collection of information for the implementation of the inventory process specified above. As part of the project, an attempt was made to inspect the railway siding KWK-Mysłowice. As part of the work carried out, various possibilities of recording video material illustrating the condition of the railway infrastructure and the possibility of creating an orthophotomap for railway infrastructure areas were analyzed and tested.

2. Aviation law

In Poland, the use of unmanned aerial vehicles is regulated by the Aviation Law Act **of 3rd July 2002** [6], as well as the regulation of the Minister of Transport, Construction and Maritime Economy of 26th March 2013 [5] and the regulation of the Minister of Infrastructure and Construction of 8th August 2016 [4].

Commercial flights using unmanned aerial vehicles may only be performed by authorized operators possessing UAVO (Unmanned Aerial Vehicle Operator) license which in Polish law means a certificate of qualifications for operators of unmanned aircraft that are currently issued by the *Civil Aviation* Authority. Flights performed in the operator's eyeshot require a qualification certificate for VLOS (Visual Line Of Sight) flights, while for flights out of sight it is necessary to have a Beyond Visual Line Of Sight (BVLOS) certificate.

According to Polish law, many rules and requirements are imposed on the UAV operator, which must be met before the flight is begun He is obliged to check if the area of the flight is not one of the forbidden zones or zones that require permission from the appropriate airspace management unit in the area. Relevant systems installed on the UAV should send warnings about approaching protected areas, however their wrong indications do not absolve the operator from the obligation to comply with the imposed restrictions. Violation of prohibited areas of the airspace is punishable. The operator is responsible for the use of the equipment and regular software updates, as well as his mental and physical condition should allow operations to be carried out safely. In addition, the operator is required to have adequate knowledge of the rules for the use of airspace and awareness of responsibility in respect of compliance with restrictions in airspace. The operator is also required to have civil liability insurance for commercial flights.

3. Analysis of organizational activities

Preparation of field tests for the flight over the railway infrastructure with the use of UAV should start with checking the availability of the airspace above the given area and analysis of the flight route. In an uncontrolled space, where it is possible to perform flights without permission and notifications from appropriate departments, there are parts of controlled spaces, i.e.: TMA (Terminal Control Area), CTR (Control Zone), MTMA (Terminal Control Area) and MCTR (Military Control Zone) and others, in which UAV flights are banned or can be carried out with the consent of the manager and under the conditions set out by him. In such case, the operator is obliged to report such intention to perform a flight to the air navigation service provider (in Poland - PANSA Polish Air Navigation Services) and if necessary, request the consent from the facility manager.

During the preparation of the flight plan, the most sensitive elements of the infrastructure should be identified and analyzed for possible flight routes. While developing the final version of the scenario, all restrictions related to the constraints of the flight and the procedures used in the facility should be considered. In case of flights within the railway line, special attention should be paid to the elements of the electric traction infrastructure and rolling stock. On railway sidings, the number of such threats will be even greater.

Afterwards it is substantial to choose the right day for testing. Weather conditions have a significant impact on the success of the inspection, because they affect the safety and quality of the conducted tests. Too much insolation can cause the sun rays reflection on the infrastructure, which can lead to deterioration of the quality of the taken images. Too large gusts of wind and intense rainfall may prevent the UAV from staying airborne and flying in a straight line, or even lead to destruction of the equipment. Despite the safety and stabilizing systems installed, a minimum, safe distance from the tested object should be maintained. The minimum distance from the elements of the power infrastructure, which takes into account electromagnetic interference, control errors or a sudden gust of wind is 5 m.

4. Conditions for recording video material

4.1. Ways of recording

The project uses two forms of the photos and video recording:

- remotely controlled flights, in which the drone is manually controlled by operators, and the image is recorded in the form of video,
- semi-autonomous flights, the purpose of which is to create an orthophotomap, which maps the area of the siding in the form of a cartographic map.

4.1.1. Remotely controlled flight

A remotely controlled flight is a flight mode in which the operators manually control the drone. It is a method that requires the creation of a precise scenario, containing all the elements of the infrastructure in detail, along with the order in which they are recorded. Performing this type of flight is complicated from the point of view of maneuvering a drone. The operator must safely avoid various types of obstacles appearing on the flight route (such as buildings, cables, high voltage lines, traction poles, trees, rolling stock, etc.). In addition, the drone cannot move away from the operator for more than 250-300 meters because it is lost from the field of view.

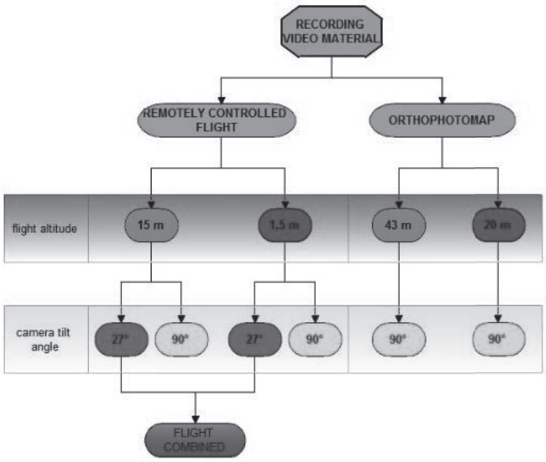

Fig. 1. Methods of material recording using UAV [own study]

From the point of view of the drone positioning needs for the process of recording video material, parameters listed below proved significant:

- flight altitude,
- tilt angle,
- speed.

In the case of a remote flight, the tested altitudes are 15 m and 1.5 m. These heights were determined by elements of the traction network, forcing a flight under or over traction. Table 1 presents the advantages and disadvantages of the flight with such parameters:

Table 1. Advantages and disadvantages of carrying out the flight under and over the overhead contact line [own study]

	Under traction	Over traction
Advantages	More detailed picture of the track infrastructure (track, rails, turnouts, drives)	The ability to speed up the flight (higher speed) In the frame there are elements of the infrastructure that rise vertically (traction, signaling, poles)
Disadvantages	Some parts of the track may be pledged by rolling stock or wagons (and others) which may hinder or prevent passage over this section. Requires a great skill of the operator. For railway traffic control devices (especially signaling devices) it is necessary to perform detailed flight routes.	The flight must be performed a few meters above the traction due to potential interference emitted by the contact wire. The traction network and its supporting structures may obscure some elements in the track

The angles that were taken into account in the analysis are: 90 ° (perpendicular to the surface) and 27 °, 45 °, 60 °. It can be generally stated that individual angular variants allow for observation of various infrastructure elements and should be selected individually. All items with height require filming at an acute angle.

4.1.2. Orthophotomap

Orthophotomap [7] – a map, the content of which is presented with an aerophotographic image (usually aerial or satellite images of the Earth's surface) processed with differential method and presented in relation to the coordinate system of the assumed cartographic mapping. In other words, a set of processed aerial photographs, adjusted to a uniform scale and fitted to geodetic control (photogrammetric) points.

An orthophotomap as opposed to aerial photography is characterized by:

- orthogonal projection (not middle),
- a uniform scale for the entire surface area (however, the scale does not have objects protruding above the ground surface, eg houses, trees).

An orthophotomap is created by:

- internal orientation of the photos, as well as mutual and absolute orientation (aerial triangulation),
- obtaining a numerical terrain model,
- orthorectification or geometric correction of photographs (repositioning of image pixels resulting from denivelation and the properties of the middle projection),
- mosaicking, ie combining ortho-images according to some sectional cut,
- rasterization with vector content (details, frames and post-border descriptions).

Before starting the creation of the orthophotomap, it is necessary to determine the numerical model of coverage of the examined area and the height at which the flight can take place in a safe manner.

The flight takes place in a semi-autonomous manner - the operator programs the route before the start, entering data into the UAS on-board computer. After the start, the drone is guided by an automatic pilot and positioned using GPS, but at any moment control over the UAS can be taken over by the operator.

Telemetry data (coordinates, altitude, etc.) are assigned to the acquired photos and movies.

An analysis of practical experience indicates that the benefits of using an orthophotomap are as follows:

- there is no need to develop a scenario before the flight, it is enough to specify the area of interest,
- relatively fast flight time,
- there is no need for direct access for the filming crew,
- in comparison to the video material from the remote flight, the orthophotomap does not require any additional processing, it is a convenient document for use.

However, this type of material also has its disadvantages:

- limited image accuracy from safe heights (eg 43 m),
- inaccuracies related to the combination of photos,
- overriding selected elements by higher objects,
- map preparation time - a few days using expensive software and a computer with high computing power.

4.2. The substantive basis of the conducted research

The subject of the research was to determine the possibility of performing the assessment of the technical condition of the railway infrastructure elements on the basis of multimedia materials: photos and films.

The analysis was based on the requirements described in the instructions issued by PKP Polskie Linie Kolejowe S.A. As part of the project, the elements of the infrastructure were analyzed, which can be diagnosed visually. The following fragments of the instructions constituted the basis for planning the tests:

- Manual on visual inspection, technical tests and maintenance of turnouts Id-4 chapter - rules for conducting technical tests of turnouts [3]:
  - for turnouts, including its basic elements, ie: switchgear, connecting rails, crosstalk, closures and adjustment devices, travel guides, etc.
- Instruction on supervision of railway lines Id-7 (D-10) - chapter III - detailed duties of the circling ranger [1]:
  - railway surface, including rails, splints, anchors, attachments, dehydration, ballast condition, etc.,
  - for railroad crossings, including bedding, road surface, visibility triangle, drainage, etc.,
  - for power, traction and automation devices, including teletechnical and power line poles, trackside indicators, sensors, containers, cable boxes, cabinets, insulated connectors, backplane contact line return connectors, SHP (train point interlock devices), cable ducts, etc.,
  - maintenance, inspection and repair instructions for current traffic control devices Ie-12 (E-24) - scope of general external inspections, signaling devices, driving routes, switch-over and derailing machines, both mechanical and electrical, sidetracks, crossing devices, etc.,
- Maintenance, inspection and repair instructions for current traffic control devices Ie-12 (E-24) [2] - scope of general external inspections, signaling devices, driving routes, switch-over and derailing machines, both mechanical and electrical, sidetracks, crossing devices, etc.

Based on these documents, the so-called check tables, based on which the assessment of individual infrastructure elements was analyzed. The tables have been constructed in such a way that each row contains:

- element (subassembly) of a given type of railway infrastructure object,
- faults to be noted when checking them.

Then the criteria and the scale of grades were defined.

Table 2. Sample records of the check table for the railway signaling device [2]

The scope of visual inspection of signaling devices		
No	**Specification**	**During visual inspection of signaling devices, check:**
1.	**2.**	**3.**
1	Sewing / grounding	check if the mast's tailing or earthing is corroded or broken.
2	Protective shields	check for signaling devices on tracks with electric traction or protective shields and their metallic connection with the mast is not corroded or damaged.
3	Head	check that the head is attached to the mast in a way that prevents it from moving.
4	Ladder	check if the ladder and protective basket are attached to the mast in a way that prevents them from moving.

5. The operational scenario of the study

Before the beginning of a flight, its route should be planned in detail. This has a significant impact on the organization, time consumption and thus the cost of the entire project.

Precision flying requires the route to be carefully planned, especially when it comes to flight modes where the flight is performed at a lower altitude, i.e. at a height of 1.5 m or in a combined flight. Such a low altitude makes part of the infrastructure elements rising above this height becomes invisible and must be recorded in separate flight sequences. For the purpose of recording elements such as switches, signaling devices, etc., it is necessary to develop separate mini-scenarios in which objects are flown around from different sides in order to enable observation of flaws and defects on their entire surface. For example, a planned mini-scenario for a signaling device is shown in Fig. 2.

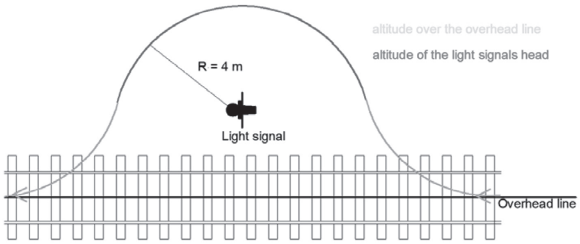

Fig. 2. The planned mini-scenario for a signaling device [own study]

In case of taking photos to create an orthophotomap, the preparation of the operational scenario is much simpler which is a great advantage of this flight mode. It only requires designating the area that we are interested in and making sure that there are no obstacles at the height at which the photos are to be taken. The operator enters the boundaries of the designated area into the drone software (setting as well the basic parameters, ie flight altitude, frequency of taking pictures or the density of the flight grid) and starts the autonomous flight. The rest of the process, including the stopover, happens by itself (the operator only needs to replace the batteries).

The documentation necessary for planning the route is a schematic plan of Railway Traffic Control (RTC) devices as well as a plan of the siding or of the section of a railway line. The first allows you to sketch the exact course of the route and allows you to easily find important elements from the point of view of conducting the flight, ie signalers, excursions, turnouts and tracks, and whether these tracks are electrified or not (which has a significant impact on the flight). The schematic plan additionally turns out to be very important at the stage of subsequent analysis of the video material, as it allows to identify the said elements and assign them the appropriate name and number (record keeping). The situational plan allows for the precise location of elements, both those that are in the schematic plan and in particular those that do not exist, i.e. distances between individual elements, mileage of tracks and other elements, support structures of the traction network and other more detailed elements. Situational plans may be supplemented with satellite maps available on the Internet. A measure, which allows to determine the distance between any two elements in the map area or the size of a given surface turns out to be a very useful tool, both when creating a scenario for the implementation of an orthophotomap and for its subsequent settlement.

When planning a flight route, there are many factors to consider. One of the most important are different types of obstacles that may occur along the route. Among them, the following have been identified:

- Hanging wires, such as telephone lines, cables, catches, etc. which may be dangerous due to their poor visibility from a distance.
- Power lines, in particular high voltage lines - dangerous due to interference emitted by alternating voltage - can significantly affect the controllability of the drone.
- Traction network: although the interference from the DC power source is not as strong or dangerous as in the case of alternating current, drone operators often prefer not to risk flying in its vicinity. Moreover, the occurrence of the track line over the given track affects the height of the drone's flight, as it must be made above or below the traction.
- Gantries, towers, other industrial infrastructure.
- Pipelines, since they can significantly reduce visibility, which makes further displacement and division of the scenario area into even finer parts necessary.
- Trees and their branches, it is an obstacle dangerous because of suscepitibility to even gentle gusts of wind, making their position not very "predictable". Especially dangerous in places where the electrified monorail line is covered with trees from both sides, and the operator is forced to maneuver the drone between the branches and the running wire.
- Passing rolling stock or rolling stock standing on tracks: an obstacle dangerous when performing flight modes at low altitude (under the traction level). The solution reducing the risk of damage to the drone (as well as increasing the safety of the filming crew) is proper communication with the signaller in the interlocking control.

The final effect of the scenario should be the photographs shooting schedule which should be strictly followed during their implementation.

It should take into account the following times:

- time of preparation for the flight:
  - time of area recognition,
  - time of laying out the equipmen,
- time of flight:
  - the start time,
  - the recording time,
  - time of return and landing,
- time to move between points,
- battery charging time,
- time for breaks and rests.

6. Inspection of the railway signaling device

The vast scope of research carried out as part of the Dron-monitor project, causes that only sample parts of the inspection will be presented in this article. As an example of the possibilities offered by the technology, a traffic light signal will be presented. A light signal is understood to be a track-side device for the transmission of optical signals relating to railway traffic. For them, we can make/check compliance with requirements on three different issues:

- general technical condition of the signal device (subject only to visual inspection),
- the correctness of the aspects,
- the visibility of the aspects from the required distance.

The following part of the article will discuss selected aspects of all the three bullets.

Fig. 3. The shunt signal [own study]

For the purpose of technical condition checks, the photographs were taken and analysed for a flight mode taken at an altitude of 15 m and a camera tilt angle of 27°.

The first element that is recommended to check in the maintenance manual [2] for the signaling devices is the return wire or ground wire (shown in Fig. 3). The recorded image from the deck of the dron hardly makes it possible to check the corroded state of the wire from this height due to the low resolution of the image for this element. However, by excluding small cracks it is possible to determine quite effectively whether the continuity of the cracks is preserved. The problem with viewing it, is that it is often hidden underground. As a rule, the image allows to determine only the end connections of the cable to the light signal base and the rail. A similar obstacle to establishing its condition is vegetation. The state of vegetation growth in the area of infrastructure is an element that can be effectively assessed by means of drones inspection.

Fig. 4. Return wire of the shunt signal [own study]

The head is the most important part of railway light signal - it contains signal units equipped with optical systems responsible for transmitting the signal to the incoming driver. The captured image allows you to effectively check if the head is properly attached to the mast, but in reality, it does not allow you to check if it is securely fixed so that it cannot be moved (as instructed by the instructions),

Fig. 5. The head of the shunt signal [own study]

The door ensures that there is no foreign interference in the signal chambers and protects them from external light. Recording allows you to check whether the door is not completely open, but does not give you certainty about the light falling in.

Recordings give a very good possibility to determine the paint coatings of the device. They allow to diagnose any possible loss of paint coatings without any problems, however, it also depends on the direction of dron's flight. It is also possible to check whether the mast is vertically positioned.

With regard to checking the correctness of aspects, dron allows for trouble-free checking of practically all requirements specified in the manuals [2]. However, the essential prerequisite is that the dron should be placed directly opposite the signal units at the level of chambers and the camera lens on board must be directed directly towards them. This may be an integral part of the miniscenarios described in the previous sections. Of course, the best position is when the dron is as close as possible to the signal head. The picture below shows this position. It shows that checking the correctness of aspect of signal is correct even at presence of high intensity of sunshine.

Fig. 6. A shot to test the correctness of the signaling aspects [own study]

The aspects of the signal can be changed in two different ways: automatically (by activating or releasing the track section behind it) or by the signalman with the buttons of the control panel from the signalling box.

In the first case, the correctness of the displayed aspect can be checked by simulating the passage of rolling stock across a controlled section, but this is not always possible. It is often necessary to use real rolling stock such as draisines.

For aspects that are not set automatically, it is necessary to synchronize them with the operations of the signalman. Good communication with the signal box is required here. The presence of computer interlocking devices equipped with data recorders will be very helpful for image analysis. Recorders allow to obtain detailed data related to aspects change sequence. These data can be compared at the analysis stage to the aspects of the individual light signals.

Testing the correctness of aspects of the signal with the use of drones allows for checking the following parameters:

- frequency of blinking light,
- no dimming of continuous light when two lamps are displayed, including one flashing,
- the presence of flashes,
- presence of doubtful signals,
- proceed on Sight Authority (PoSA) extinction time,
- consistency of displayed signals for specific route paths and traffic situation.

The last aspect examined for the light signals is the visibility of their aspects. The PKP PLK requirements [2] require to check the visibility of the aspect of the signal from a position next to the right railway line, looking in the direction of travel, at a distance equal to the minimum visibility of signals of the signal. The visibility of aspects depends mainly on the highest permitted speed of trains approaching the signal and should be depending on the type:

- for home signals from 100 to 400 m (depending on the line category),
- for exit signals for which routes are carried out without stopping - not less than 200 m,
- for signals situated on the lines of local significance - about 50 m,
- for distant signals and level crossing signals not less than 200 m,
- for shunt signals not less than 50 m,
- for signal strips and indicators not less than 200m.

Although these distances may appear to be small and the image of the recordings (4K resolution) were made of very high quality, the research has clearly shown that it is not possible to check the visibility of the signals from the required distances. It turned out that even at such high resolutions, the light source being an aspect becomes a stain on the image very difficult for evaluating. The picture below shows two home signals recorded from a distance of 250 m.

Fig. 7. A frame from the recording of entry signals from a distance of 250 m [own study]

7. Conclusion

Unmanned aerial vehicles allow automation of tasks related to monitoring of large infrastructure facilities. The "Dron-monitor" project was launched to assess the possibility of using UAVs for automation of railway infrastructure inspection and stocktaking based on collected multimedia materials. Various possibilities of recording video footage depicting the state of railway infrastructure were tested, as well as the possibility of creating orthophotomaps for railway areas.

Preparation has started with a check of the airspace availability of the siding area and flight route analysis. During the preparation of the flight scenarios, the most sensitive rail infrastructure components were identified and then analysed for possible flight routes. For this purpose, track diagrams, situation plans and satellite maps were used. The final effect of developing the scenarios was the schedule of taking pictures.

The project involved remote control flights, in which the dron was controlled manually by the operators, and the recorded image was recorded in the form of video recordings as well as semi-autonomous flights, the purpose of which was to create an orthophotomap, imitating the siding area in the form of a cartographic map.

During the analysis of the collected data, the requirements described in the manuals issued by PKP Polskie Linie Kolejowe S. A. [1, 2, 3] were applied. As part of the project, the infrastructure elements that can be visually diagnosed were examined.

On the basis of the check tables, the possibility to assess the technical condition of particular infrastructure elements was analyzed. A railway light signal was presented as an example of the tests carried out.

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