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Application of unmanned aerial vehicles on transport infrastructure network

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Subject review

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Frequent abrupt climate changes have been increasingly causing landslides on the transport infrastructure network. Traditional mapping methods, and methods for determining the volume, cross-sections, contours and other parameters needed in the rockfall engineering analysis, can be modified, improved, and even completely replaced, by means of unmanned aerial vehicles. The possibility of using drones for evaluating condition of the transport infrastructure network, with an emphasis on their advantages and disadvantages, is explored. The legislation and research initiatives for the use of drones are presented.

Key words:
rockfalls, Unmanned Aerial Vehicles, transport infrastructure, point cloud, ortophoto maps

Pregledni rad

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Primjena bespilotnih letjelica na prometnoj infrastrukturnoj mreži

Učestale nagle klimatske promjene uzrokuju sve veću pojavu odrona na prometnoj infrastrukturnoj mreži. Primjenom bespilotnih letjelica mogu se dopuniti, poboljšati, pa čak i u potpunosti zamijeniti klasični načini kartiranja, određivanja volumena, poprečnih presjeka, slojnica i drugih parametara koji su potrebni za inženjerske analize odrona. U radu se prikazuju mogućnosti korištenja bespilotnih letjelica u ocjeni stanja prometne infrastrukturne mreže, ističući njihove prednosti i nedostatke. Prikazana je zakonska regulativa i znanstvenoistraživačke inicijative za primjenu bespilotnih letjelica.

Ključne riječi:
odroni, bespilotne letjelice, prometna infrastruktura, oblak točaka, ortofoto karte

Übersichtsarbeit

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Einsatz unbemannter Luftfahrzeuge im Verkehrsinfrastrukturnetz

Häufige kurzfristige Klimaveränderungen verursachen ein vermehrtes Auftreten von Erdrutschen im Verkehrsinfrastrukturnetz. Durch die Anwendung unbemannter Luftfahrzeuge können herkömmliche Vorgänge zur Kartierung und Ermittlung von Volumen, Querschnitten, Höhenlinien oder anderen Parametern zur technischen Analyse von Erdrutschgebieten ergänzt, verbessert oder sogar gänzlich ersetzt werden. In dieser Arbeit werden Möglichkeiten zur Anwendung unbemannter Luftfahrzeuge bei der Zustandsbeurteilung von Verkehrsinfrastrukturnetzen beschrieben und ihre Vor- und Nachteile erläutert. Rechtliche Vorschriften und Forschungsinitiativen zur Anwendung von unbemannten Luftfahrzeugen werden dargestellt.

Schlüsselwörter:
Erdrutsch, unbemannter Luftfahrzeuge, Verkehrsinfrastruktur, Punktwolke, Ortophotokarte

1. Introduction

Rapid changes of climate, the effects of which are felt in all parts of the world, have been increasingly studied over the past three decades, and are also strongly felt in the sphere of safety of transport infrastructure. The price of road and railway infrastructure is currently valued at € 9.7 trillion in the EU alone. Its maintenance requires ten times less funds compared to those needed for urgent repair of damage caused by rockfall, i.e. by sudden detachment of independent rock blocks or parts of the rock mass from steep slopes [1]. Due to an increased frequency of rockfalls, weather changes have a particularly strong effect on slopes and engineering cuttings forming part of transport infrastructure [2]. Water is one of the key factors that control stability of rockfalls. Water expands when warmed, and global warming results in the meltdown of polar ice plates and icebergs. The combination of these two changes results in an increase in sea levels. Thus some regions are increasingly affected by extreme weather conditions and rainfalls, while other areas are affected by increasingly intensive heat waves and droughts. Hot and dry summers cause shrinkage and fracturing of rocks, and the loss of vegetation, while intensive rainfalls result in rock swelling, change in infiltration regimen, higher pore pressure, erosion, and flooding. It is expected that these effects will gain in intensity in the decades to come.

Rockfalls constitute a significant hazard in areas characterized by diverse lithostratigraphic composition of soil, high level of tectonic and seismic activity, complex geological properties, diverse relief features, unfavourable weather conditions, developed water network, and significant anthropogenic influence on the formation of relief. Rockfalls of smaller or grater magnitude are frequent in the Republic of Croatia where 54 % of land is covered with karst. According to their type, Croatian karst areas are classified as the karst of moderate spreading (Dinarides, Alps, Pyrenees, Appalachian Mountains, Australian mountains, etc.) characterized by up to 8 km thick carbonate Mesozoic and Palaeogene sediments which, in addition to pronounced tectonic fracturing, contributes to similar spreading of both horizontal and vertical forms (speleological structures) [3, 4]. In Croatia, karst spreads from Slovenia in the northwest to Montenegro in the southeast, while its northern boundary runs from Karlovac toward the east, crossing into Bosnia and Herzegovina [5, 6]. A majority of Croatian motorways A1, A6 and A7, 570 km in total length, pass through a hilly terrain with numerous karst slopes cut into the karst rock. The situation is much worse on more than 2200 km of national roads and on 2796 km of railways where slopes are even steeper, closer to the road or railway, and less protected. An overview of significant rockfalls that have affected Croatian road and rail network over the past several years is presented in Table 1 [7].

Rockfall data have not been systematically collected in Croatia, although this activity could provide useful information about the size and frequency of rockfalls and thus enable proper design of rockfall protection measures in the areas most affected by this occurrence. Similarly, Croatia has no guidelines for the design of rockfall protection systems, which is why European experience and standards in this area are observed and applied. In the case of linear infrastructure facilities such as national roads, motorways and railways, an estimate of rockfall hazard is most often based on the results obtained by grading a certain number of parameters for each site where a possibility for rockfall occurrence has been identified. The highest scoring section represents at the same time the section with the highest rockfall hazard [8].

In order to address specific features of Croatian karst, appropriate methods should be developed to define input parameters, to form a data base based on former rockfalls, and to determine and verify new knowledge by in situ measurements. A rockfall classification methodology for karst area should be developed and adjusted to the properties of processes that are significant for the creation of this type of relief. A rockfall protection strategy should also be developed based on available information about former rockfalls, climate, and climate changes, and thus obtained information should be used to develop rockfall protection guidelines that would be suited to Croatian climate and geology (Figure 1).

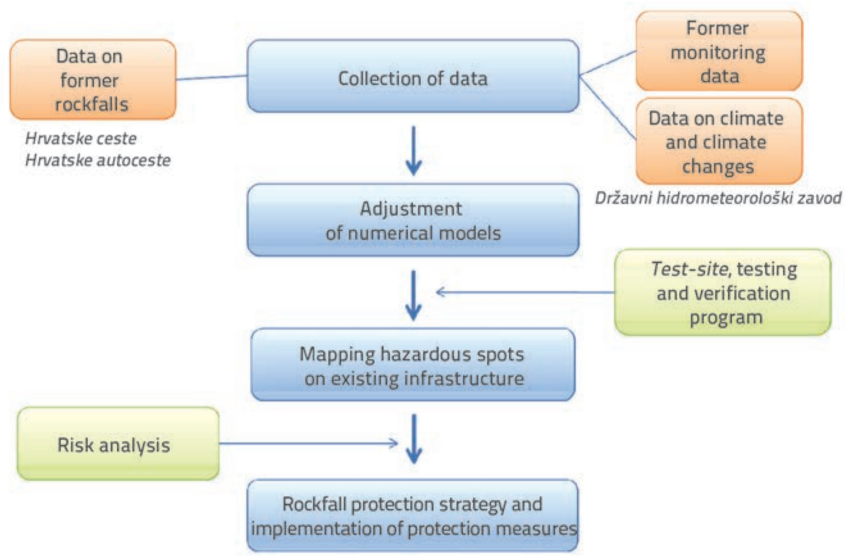

Figure 1. Development of rockfall protection strategy

2. Evaluating condition of infrastructure network

2.1. Evaluating condition of road infrastructure network

The condition of motorways is continuously inspected, analysed, and assessed by road maintenance patrols and technical maintenance units, assisted by civil and geology engineers. Maintenance activities and all other activities that need to be taken to enable proprer completion of maintenance and repair

Table 1. Rockfall examples in Croatia [7]

Locality	Characteristics			
	Bloc volume	**Weather conditions**	**Consequences**	**Protection measures**
Stupica, D512 Makarska- Vrgorac 	largest blocks about 100 and 250 m^3	rain	traffic closed for all vehicles to enable removal of blocks; development of design solution to prevent future rockfalls	rockfall protection design involving tunnel construction and protection of approach cutting with rockfall protection barriers
Brljan, National Road Oklaj-Kistanje 	data n/a	rain and wind	traffic was operated using a single lane until removal of blocks	no rockfall protection measures were taken, although smaller rockfalls had already been registered in this area
Krilo Jesenice, Adriatic Coastal Road 	largest block measures about 8 m^3	rain	material damage to cars; people injured; road closed to traffic	locality stabilised by installing a protection system formed of steel mesh, steel cables, and anchors
Oštrovica Interchange, Rijeka - Zagreb Motorway 	a total of 60 m3 of rocks fell onto the road	rain	exit in the direction of Rijeka toward Crikvenica and Krk closed to all vehicles	locality stabilised by installing a protection system formed of steel mesh, steel cables, and anchors
Buzeta to Roča railway line, Raspadalica cliff 	largest block weighs 12 m^3	rain	70 m of railway damaged (rails moved by one and a half meters); two telephone poles damaged; railway line closed	no rockfall protection measures were taken although smaller rockfalls had already been registered in this area

works are specified in the *Regular Motorway Maintenance Standard*. In addition to this *Regular Motorway Maintenance Standard*, operators also use the Structure Management System (SGO), consisting of the procedures and methods for the collection and analysis of structure-related data, in order to anticipate future condition of structures and their maintenance needs, and to enable long-term planning/management of funds to be allocated to maintenance activities.

Road maintenance patrols conduct around the clock inspections to determine the passability and usability of motorways, in accordance with the corresponding regulations. This patrolling activity can only be conducted by qualified and professionally competent persons (maintenance patrollers). During road inspection activities, maintenance patrollers inspect condition and passability of motorways, and note any extraordinary events and weather conditions of significance for the operation of motorway traffic. Motorway inspections are conducted at least once a week by Technical Unit Managers and Route Managers, while roads must be inspected at least three times a week (and preferably daily – on working days form Monday to Friday) by Maintenance Foremen. In the ice thawing or strong rainfall season, or in other cases when motorway stability and traffic safety is endangered (flooding, rockfalls, sliding, torrential downpours, etc.), the inspection of motorway passability and usability must be conducted in accordance with the estimation of real hazard to motorway. These inspections can be seasonal, annual, principal, and extraordinary.

Seasonal inspections are made by competent Technical Maintenance Units two times a year, normally after winter (March – May) and in autumn (September – November). Seasonal inspections are visual inspections only and their scope is limited to readily accessible elements. They are aimed at checking condition of traffic areas, structural elements of transport facilities, road bed (substructure) and drainage facilities, equipment, etc.

Annual inspections are conducted by competent Technical Maintenance Units in the presence of a civil engineer and a geologist (from the motorway maintenance service). Each annual inspection must comprise visual inspection of all structural elements. The annual inspection report contains description of structural parts that have been inspected, type and level of damage identified in the course of inspection, and the extent of the area affected by damage, with a detailed description of the area and with photographs of each damaged spot.

Principal inspections are conducted by a team of experts in the field of civil engineering (certified civil engineers with at least five years of working experience in the company on assignments involving principal inspection of structures). These inspections are coordinated ty the team leader who is capable, due to his qualifications and experience, of adapting inspection procedures to the actual on-site situation, and of interpreting the results in a competent way. The inspections are conducted once every six years based on the time schedule defined in advance.

Extraordinary inspections are conducted by the persons similarly qualified as the ones conducting principal inspections. The scope of such inspections corresponds to the scope of principal inspections but may also include basic investigation works (if such investigations are deemed necessary). The content and scope of extraordinary inspections of roads is determined by Road Manager who is appointed by the Road Inspection Committee.

2.2. Evaluating condition of rail infrastructure network

Continuous inspections, analyses and railway condition assessments are conducted by the maintenance patroller and the inspection team manager, together with their associates, the aim being to detect any changes that are likely to affect traffic safety. The maintenance patroller inspects the railway on foot on the daily basis. Based on such everyday railway inspections, the maintenance patroller submits his *Maintenance Patroller Report* for each month in a year. The report covers only the days on which some interventions had to be made, i.e. removing soil from gutters, advising about sign collapse or repairing such signs, reporting on problems with switches, reporting on rockfall, etc.

The inspection team manager and his assistants conduct railway inspections once a month on foot, two to three times a month using a motor trolley and, in the period from 1 June to 30 September, they conduct additional railway inspections several times a month using a heavy-duty motor trolley. Based on such railway inspections, the inspection team manager and his assistants keep a "*Register of monthly rail and rail structure inspections and measurements*". In this register, they note everything significant that they have observed during visual inspections conducted on foot, using a motor trolley, or a heavy-duty motor trolley, including also any observations relating to fire protection within the right of way, and visual inspection of switches. The information about the inspection date, and the name of patroller who conducted the inspection or measurement, must also be entered in the register. The rail condition assessment must be made for each rail inspection.

The Inspection Centre Management also conducts regular inspections of the civil engineering infrastructure sub-system. These inspections are conducted once a month using a machine trolley. Based on such inspections, the Inspection Centre Management writes its "*Report on Irregularities Noted During Railway Inspection*".

Structures and facilities for which inspection times have not been specified are regulated by Bylaw 315. According to this Bylaw, inspections are made occasionally according to the needs and possibilities, depending on the scope of other activities, or following on-site information about irregularities noted on such structures. Bylaw 315 regulates maintenance of track substructure, which includes the trackbed, bridges and culverts, tunnels, railway station facilities, and structures for the protection of railway against surface water and weather influences. This maintenance implies keeping register about: technical and other data, permanent supervision, occasional inspections, testing, and measures aimed at timely identification and removal of irregularities and damage. Cuttings are regulated by Article 7 of Bylaw 315. Procedures to be applied for locations presenting a permanent rockfall hazard are defined in Section 4 of the mentioned Article 7. Section 9 regulates measures to be taken in case of slopes made of material nonresistant to weather influences, while provisions related to keeping register of unstable slopes are given in Section 10.

2.3. Current experience in assessing condition of transport infrastructure

Present approach to the analysis of rockfalls in case of linear infrastructure facilities requires knowledge of geometrical and mechanical properties of rock slopes and rock blocks. Mechanical

Figure 2. Geological alpine mapping of potentially unstable blocks at the road D512 Makarska – Ravča

properties of rock slopes and rock blocks can be determined by laboratory and in-situ testing, while geometrical characteristic scan be defined through in-situ measurements only.

If the terrain is inaccessible, direct measurement of slope inclinations can be very difficult and sometimes even quite risky. One of the ways in which this activity can be conducted is through geological alpine mapping of potentially unstable blocks, with determination of rock block volume, as shown in Figure 2. This work can only be performed by persons specialized for the conduct of such hazardous activities.

Visual inspection of terrain on such inaccessible locations, and collection of 3D data by traditional geodetic methods, can result in incomplete and insufficiently detailed representations of the terrain, because a considerable quantity of measurement data is needed for a good-quality description of such locations, which can not be obtained without a direct contact with the object that is being measured [9]. Due to advances in technology, considerable changes in the way data are collected were made in the second half of the twentieth century thanks to development of photogrammetry. A huge step forward has been made by development of laser scanning that enables automatized collection of a huge quantity of data. Laser scanning or "3D laser scanning" is also known as LiDAR (Light Detection and Ranging). It is based on knowledge of the speed of light and a narrow coherent laser beam that the device emits into space. The beam (impulse) reflects from the structure at the speed of light, and returns to the receiver component of the

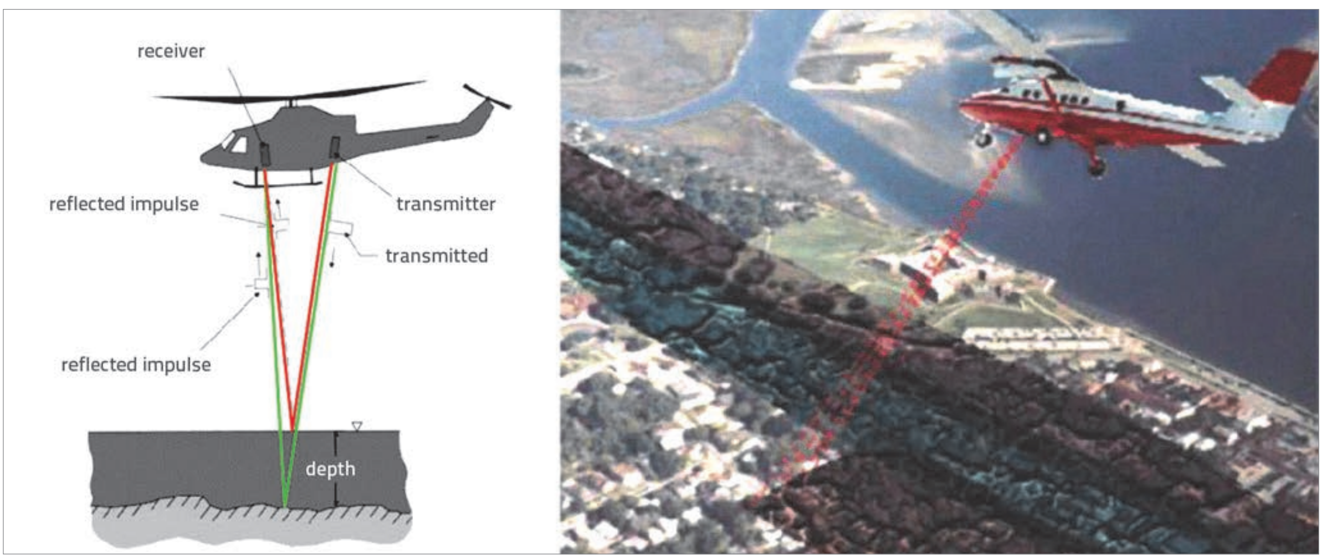

Figure 3. ALS survey principle, [11]

Figure 4. Replacement of traditional determination of rock block volume by remote sensing via unmanned aerial vehicles

device. The device measures the time interval the impulse needs to pass from sensor to obstacle and back. The distance is calculated from time measurements. Once the first impulse is measured the scanner sends, via a rotating mirror or by turning the housing, the second impulse a bit more horizontally (or vertically, depending on the scanner type) compared to the preceding impulse. The angular displacement value is obtained for each measured point as related to the starting point by adding the previously operated constant displacements [10]. x, y and z coordinates can be defined using the measured distances and known space angles. The process is repeated a thousand times per second and so the distance data are obtained for a million of points on the observed structure, and these points form a point cloud. The final result is an accurate and precise 3D space model that can be used to determine the orientation, length, distance and unevenness of discontinuities and the block size.

Two laser scanning technologies can be differentiated: terrestrial laser scanning (TLS) and airborne laser scanning (ALS). In the case of ALS, an airplane with the attached scanner flies over the area to be surveyed. In order to obtain an image of the entire area it is necessary to determine in advance the width (array) of the area to be surveyed, as related to the angle of vision of the scanner and height at which the flight is operated, and to fly over the area several times in the required number of arrays (Figure 3). An overlap must be made between individual arrays so as to ensure that the entire area is covered by the survey and to equalise all arrays in the block, both vertically and horizontally [11]. The polar method is used to determine spatial coordinates of individual measurement points.

Unlike the terrestrial laser scanning device, the ALS scanner can accurately map large areas, which enables the conduct of structural analyses at a regional level in a much faster and safer way, without entering the hazardous zone. In addition, it can be used to determine the input data for the analysis of rockfall risk using the Rockfall Hazard Rating System (RHRS), such as the orientation of discontinuities, size of blocks, slope geometry, and block position [8].

The ALS can be used in inaccessible areas, in areas that are not suitable for humans due to high temperatures or unfavourable concentration of hazardous gases and, in case of road or railway survey, this activity can be conducted without interrupting the traffic. However, the price of this survey is still very high and a competent personnel is needed, not only for the survey and data analysis, but also for operating the plane or helicopter.

However, in order to obtain data by remote surveying, unmanned aerial vehicles can nowadays be used instead of a plane or helicopter, and these unmanned devices can significantly reduce the scope of field work, save a lot of time, and bring down survey costs. Traditional methods used for mapping, defining volumes, cross-sections, contour lines, and other parameters needed for engineering analyses, can be greatly enhanced, improved and even fully replaced by the use of unmanned aerial vehicles. An example of the way in which traditional procedures for determining a stone block volume can be replaced quite simply by an unmanned aerial vehicle is shown in Figure 4.

3. Use of unmanned aerial vehicles

An unmanned aerial vehicle (UAV), popularly known as "drone" (Figure 5), is a flying device or aircraft without the crew that can be remotely operated by remote controller, or that can fly independently using a prescheduled flight plan [12]. Although these devices were primarily developed for military purposes, they are now increasingly used in various fields of research and economy. Based on the size, weight, flight time, flight distance and altitude, the UVS International defines three main categories of drones: tactical UAVs, strategical UAVs, and special task UAVs [13].

Figure 5. Unmanned aerial vehicles in flight above railway line

Unmanned aerial vehicles, equipped with devices for various uses, presently meet economic and all other requirements for a highly reliable airborne collection of data, thanks to development of the global navigation satellite system (GNSS), inertial navigation system (INS), digital cameras, and various mobile sensing devices. Unmanned aerial vehicles that are to be used for aerial survey of terrain must meet the following basic requirements: realisation of planned flight as defined prior to the survey, capacity to carry survey and navigation equipment, appropriate flight autonomy, and the possibility for absorbing vibrations and other external influences during flight [14]. Given a great range of various sensors they can be equipped with, from various high-resolution cameras for taking photos and making video recordings, to thermographic and multispectral cameras, gas detectors, and various mobile laser scanners, drones are increasingly becoming an ideal tool for the collection of topographic and spatial data that can be used, based on appropriate algorithms, to create various 3D models of a structure or an area. Unmanned aerial vehicles have already proven to be quite useful for monitoring propagation of wildfires and floods, for discovery of persons in distress at hardly accessible sites, supervision of traffic and infrastructure, monitoring of industrial facilities and their critical spots, supervision of national borders, etc., where drones enable rapid collection of data that can be highly useful in crucial decision making processes.

3.1. Use of unmanned aerial vehicles at the European and worldwide transport infrastructure network

Despite various approaches to legislation relating to the use of unmanned aerial vehicles in Europe and in other parts of the world, the use of such unmanned devices for the survey of the road and railway infrastructure network has been increasing considerably in recent years.

Niethammer et al. [15] used an unmanned aerial vehicle equipped with a digital camera to monitor slow movement of the Super-Sauze landslide in France, and demonstrated its competitive edge compared to other methods for remote mapping of landslides. A similar use is presented by Carvalaj et al. [16] in the survey of a landslide along the motorway embankment in the region of Almeria in Spain. The use of drones on a motorway rehabilitation project in Friedewald, Germany, is presented by Siebert and Teizer [17]. Kovačević et al. [18] presented the use of unmanned aerial vehicles in the design of rockfall and landslide improvements along national road and railway infrastructure.

Dutch railway company ProRail [19] uses unmanned aerial vehicles equipped with infrared sensors to check operation of the heating system used on their railway switches. Network Rail, the company that operates railway network in the United Kingdom, signed in 2014 a general agreement with four companies for survey services based on the use of unmanned aerial vehicles in order to improve maintenance of railway lines, increase efficiency of its employees, and reduce the quantity of work at elevations, which was required quite frequently. In addition, images obtained during this survey will be used to regularly update the maps collected in the scope of the ORBIS project (Offering Rail Better Information Services) [20], which will enable formation of 3D models and derivation of cross-sections from the survey images, as described in more detail in the following Section. An interesting use comes from Germany where the national rail company Deutsche Bahn [21] decided to use unmanned aerial vehicles in the struggle against graffiti along its infrastructure. French railway company SNCF [22] has been studying possible use of unmanned aerial vehicles for preventing copper theft from cables along railway lines.

The Federal Aviation Administration (FAA) [23] plays a significant role in the study of possible uses for unmanned aerial vehicles in the US transport infrastructure. Relevant studies and investigations made in several states such as Arkansas [24], Georgia [25], North Carolina [26], Ohio [27], Utah [28], Washington [29], and West Vriginia [30] have been financed through state departments for transportation (SDOT).

The largest North American railway company Union Pacific, which operates about 52,000 km of railway lines [31], is considering the possibility of using unmanned aerial vehicles that would precede human intervention, and hence optimise inspection of railway infrastructure by pointing to significant occurrences. On the other hand, the second largest North American railway company, BNSF Railway Co., which operates practically the same number of kilometres of railways as the Union Pacific, has gone a step further by obtaining in March 2015 the approval of the Federal Aviation Administration (FAA) for the use of unmanned aerial vehicles over a three-year period, for inspection of infrastructure and railway works [32].

3.2. Preparation of 3D model

In order to create a three-dimensional model of a terrain or structure, a considerable number of photographs of the area must be taken, with longitudinal and transverse overlapping between the photographs. The principal objective of the computer program is to link these photographs into a single whole, and to generate a point cloud using the following steps:

1. identify similarities between the photos,
2. derive the SfM (Structure from Motion) algorithm,
3. make geo-references,
4. finalise the process and make image changes as needed.

3.2.1. Identifying similarities between photos

According to Snavely [33] the first step toward creating a 3D model involves finding common 2D pixels between the photographs taken. Each set of pixels found to be correspondent during comparison of several photographs enables creation of one 3D point in space (Figure 6). Pixels are linked by finding and linking structures on a pair of photographs, which are then linked with the same structures on other photographs, thus creating the model on the basis of which a point cloud is generated using an appropriate algorithm.

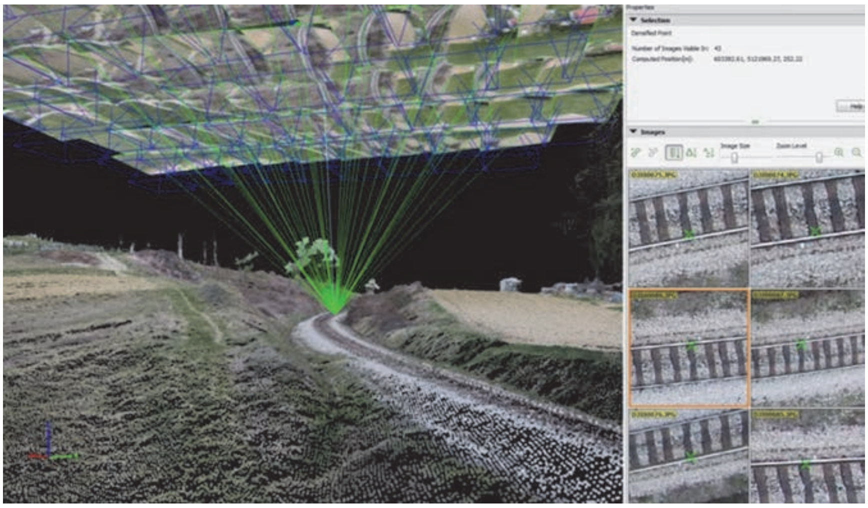

Figure 6. Correspondence of pixels from various photographs

Assuming that $F(I)$ denotes a set of structures found on photograph I, the system considers every part of the structure $f \in F(I)$ for each pair of photographs I and J and looks for its closest surroundings $f_{nn} \in F(I)$:

$$f_{nn} = \underset{f' \in F(J)}{\arg\min} \left\| f_d - f_d' \right\|_2 \quad (1)$$

After all image pairs have been linked, then the links are established between a larger number of images. For instance, if the structure $f_1 \in F(I_1)$ corresponds to the structure $f_2 \in F(I_2)$ and structure $f_3 \in F(I_3)$, they are all grouped into a set $\{f_1, f_2, f_3\}$. These sets are established by testing each structure f in every image, and the procedure lasts until all structures corresponding to one another are found in all photographs.

3.2.2. Derivation of SfM (Structure from Motion) algorithm

The next step involves implementation of the SfM algorithm through which geometry of the structure is estimated based on the sets of points defined in the previous step. This estimation is done by finding three-dimensional coordinates of points which, when linked through perspective projection equations, correspond the best to the sets that have been marked [33, 34]. For each set of points j the geometry is defined through three-dimensional points X_j. The parameter q_{ij} from expression (2) represents measured positions of bands (survey lines) j on the photograph, which is most often unknown as not all bands are visible on all photographs. The problem is solved by finding common solutions for the camera and parameters in the studied area in order to define the best possible positions of bands. For n views and m bands, the objective function g assumes the following form:

$$g(C, X) = \sum_{i=1}^{n} \sum_{j=1}^{m} w_{ij} \left\| q_{ij} - P(C_i, X_j) \right\|^2 \quad (2)$$

where: w_{ij} is the variable indicator.

If $w_{ij} = 1$ then the camera "observes" the set j. The expression $q_{ij} - P(C_i, X_j)$ is known as the projection error of a set j in the camera (Figure 7).

According to Figure 6, if a three-dimensional point X_j is projected to the camera C_i, then the projection error represents the difference in distance between the projected point $P(C_i, X_j)$ and the observed point q_{ij}, and the objective function g represents the sum of squares of projection errors "weighted" by the variable indicator. The principal aim of the SfM algorithm is to find the parameters of the camera and studied area that minimise this objective function [34].

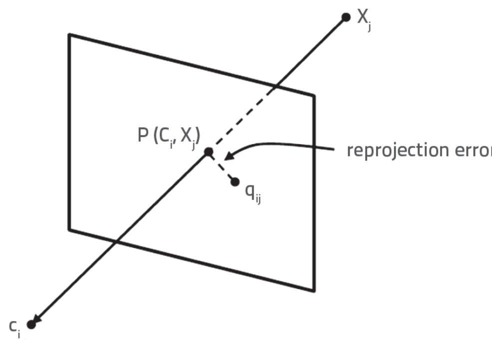

Figure 7. Projection error [15]

Images obtained from the air should have a considerable number of common points, which means that a specific distance between projection centres should exist during photograph taking so that two or more photographs can be assembled into a three-dimensional object [35]. When taking photographs, care must be taken about the required longitudinal and transverse overlapping, which amounts to 60 % for the longitudinal and 30 % for the transverse overlapping. The model is additionally improved by further processing of sets through the SfM algorithm (the process that recognises obvious point linking errors and eliminates them from the model, so that they do not affect the final result), and by conversion of the camera's focal length (parameters needed for conversion are the focal length, CCD sensor size, and photograph size in pixels).

3.2.3. Georeferencing

The SfM algorithm shows the coordinates of points in the coordinate system in which the flight has been planned, which is most often the WGS84 coordinate system as the reference coordinate system for GPS satellites, with the start in the centre of the Earth's masses. Although such representation is good for visualisation of a given area, it has to be georeferenced if it is to be placed on a map or plan of an official coordinate system. Once a minimum of three identical points are known in both systems (camera based local system, and national or global systems) then the use can also be made of the seven-point Helmert transformation of coordinates, which assumes the following form:

$$X_{GLOBALNI} = c + \mu R X_{LOKALNI} \tag{3}$$

where:

$X_{GLOBALNI}$ - point coordinates in the national or international coordinate system

$X_{LOKALNI}$ - point coordinates in the system created in the SfM algorithm

μ - scale factor

R - rotation matrix

$c = \begin{bmatrix} c_1 \\ c_2 \\ c_3 \end{bmatrix}$ - translation vector

3.2.4. Final processing and corrections

After the georeferencing, some additional steps can also be taken to improve output results. In order to remove the so called "false points", caused by inadequate linking or poorly presented geometry, the points visible on less than three photographs have to be eliminated. After that, in order to clean the geometry of points, the photos that register less than 16 points are defined, and then these points are also eliminated from the model development process. The SfM algorithm functions properly if all photos, when included in the model development process, are in the relationship in which they were at the moment of exposition (oriented as either "portrait" or "landscape"). An additional analysis is needed to determine whether a photograph has been inadequately oriented.

3.3. Point cloud

The final result of the above procedure is the point cloud that consists of a set of points in a given coordinate system. In the three-dimensional coordinate system, these points are defined by X, Y and Z coordinates, and they most often represent the external surface of an object. In addition to coordinates, the point cloud also contains the data about the lighting, time of survey, and colour of every point within the cloud. An example of the point cloud is shown in Figure 8 for the Mali Čardak quarry site near Perušić.

3.4. Use of 3D models for engineering purposes

Upon arrival at the studied site, a map of the wider area to be surveyed (Figure 9) is downloaded onto a mobile phone or tablet that is wirelessly connected to the unmanned aerial vehicles, and through which we are able to see the image shown by the camera in real time.

Figure 9. Site map downloaded to a smart phone or tablet

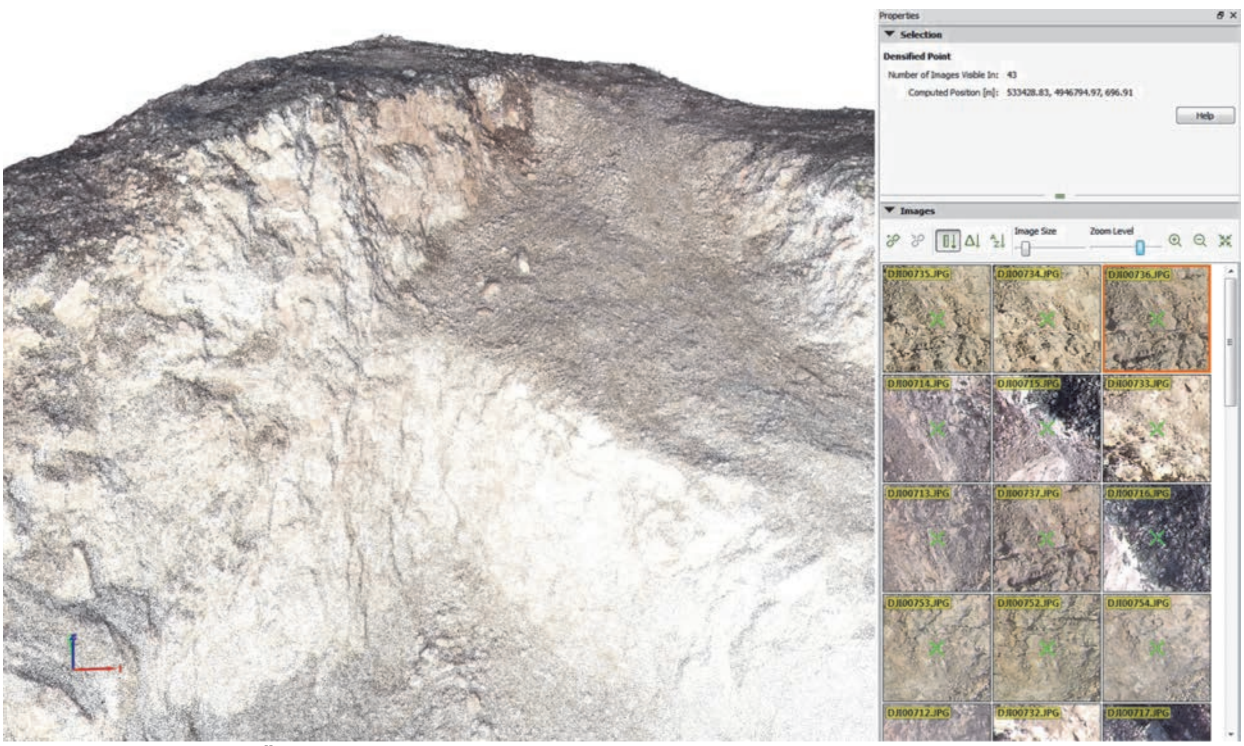

Figure 8. Point cloud at the Mali Čardak Quarry near Perušić

The following has to be defined on the downloaded map: exact and fully detailed dimensions of the area to be mapped, flight zone orientation, flight altitude, and the flying speed if the survey concerns topographic content that is relatively flat (horizontal terrain). All parameters needed for an independent flight of the unmanned aerial vehicle are thus defined, and the flying device can start collecting the data. The selection of these parameters automatically generates the flight schedule, and the points at which the camera carried by the unmanned device will take photographs are programmed in advance. At the end of the survey, the unmanned device independently returns to the starting position.

If the inclination of the ground at the site of the survey is considerable, i.e. if the terrain is vertical and steep, the free flight mode is adopted, and photographs are taken based on the predefined horizontal and vertical changes in position of the camera that is linked to the GPS antenna of the unmanned device. The experience and knowledge of the unmanned device operator is highly significance when this mode of survey is applied. Once the survey is ended, the geo-located photographs, and all other parameters needed for orientation of photos at the moment of exposition, are transferred to the photograph processing software. The transfer (downloading) of such images into the photograph processing software results in the representation of the unmanned device flight, showing also the position of each photograph taken during the survey (Figure 10). An example of the survey of the Doljani railway cutting at KM 80+830 of the railway line R201 Zaprešić – Čakovec, between the train stations Novi Marof and Turčin, where one part of the line was affected by landslide, is shown in Figure 9. The methodology for obtaining a 3D model from photographs, and for defining cross-sections and volumes, is defined below on the example of the above mentioned cutting. The computer program used in this particular case is Pix4Dmapper, which has been specifically developed for processing photographs collected by unmanned aerial vehicles [36].

Figure 12. Ortophoto map based on photos taken by unmanned aerial vehicle

Figure 10. Area traversed by the unmanned aerial vehicle and photo-taking positions

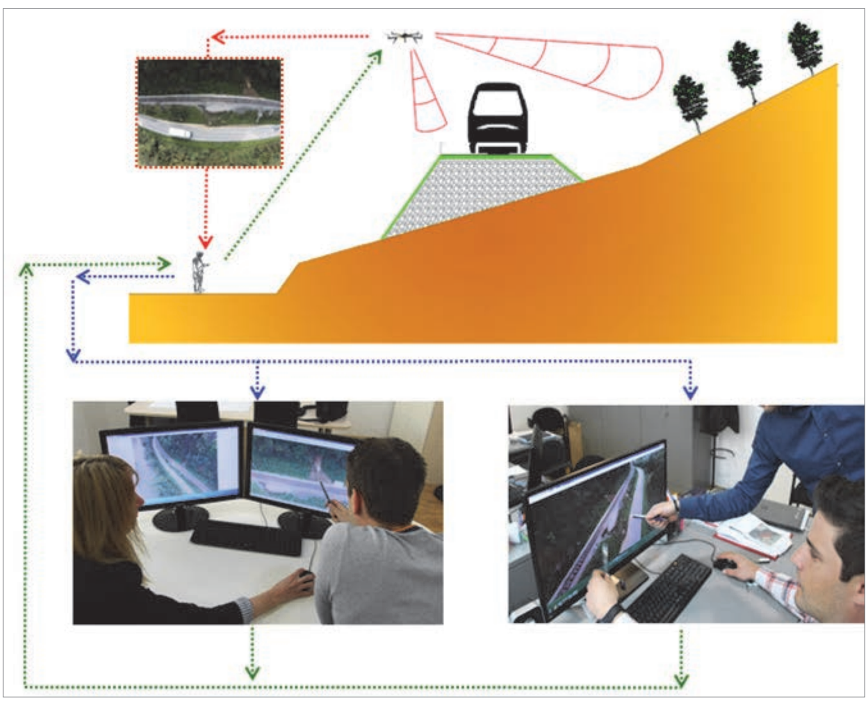

Figure 11. Interactive procedure for evaluating condition of transport infrastructure [19]

One of potential advantages of the use of unmanned aerial vehicles lies in the possibility of making an interactive evaluation of the situation at a particular transport infrastructure segment [37]. In this case, as shown in Figure 11, an

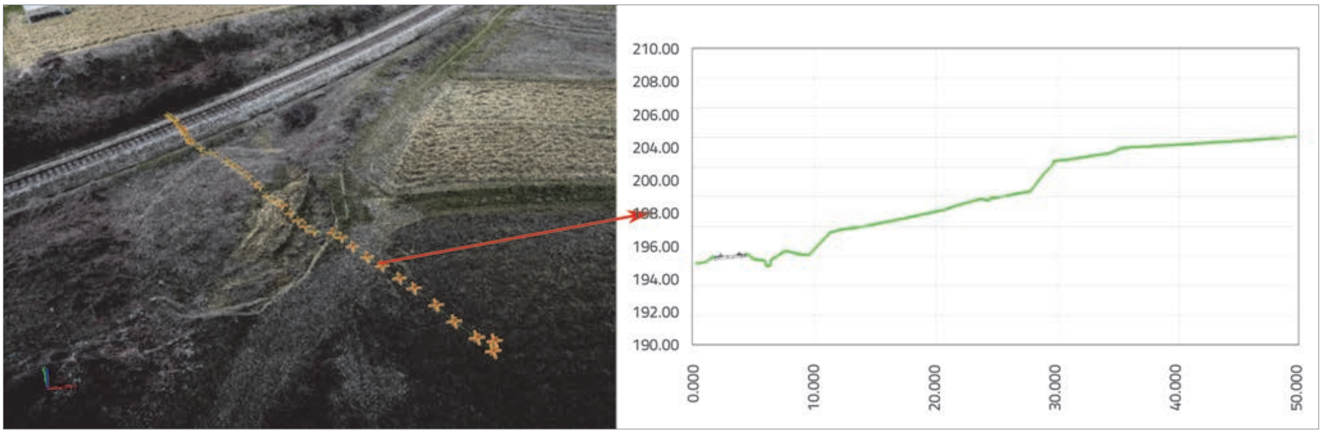

Figure 13. Defining cross-sections at Doljani cutting

operator guiding the unmanned device has to be present on the site of survey. At his display, the operator is able to see at every instant the image photographed by the unmanned devices, and can share this information in real time with persons at other locations (offices, cabinets, laboratories), so that they can also see the images taken by the drone. Thus, several persons actively participate in the survey of the slope or potential rockfall, the advantage being that the persons siting in the office can be much more focused and able to analyse the site in greater detail and better identify the problem, and instruct the on-site operator about additional images to be taken. This is much more effective than the case when the operator has to do all these activities by himself: operate the drone, take photographs, and observe and respond to potential problems at the site of survey.

Depending on the computer processor's size and its graphical performances, the mentioned 3D terrain representation can be obtained after a relatively short processing time in form of a point cloud or ortophoto map (Figure 12).

The point cloud and ortophoto map, which are fully measurable, can be used to define cross-sections (Figure 13) and calculate volumes (Figure 14) that can be transferred to CAD programs, which are readily used in most professions conducting mapping and design activities.

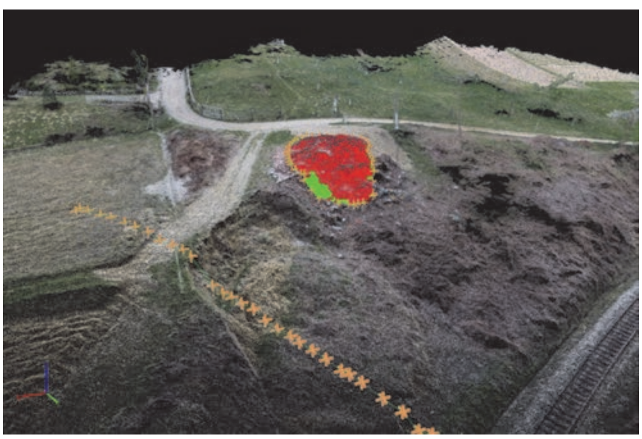

Figure 14. Calculating volumes at Doljani cutting

After transfer to the CAD or GIS program, surfaces can be generated very simply from point clouds using the TN (triangulated irregular network) algorithm, and contour lines can be generated at equidistances as desired by the user (Figure 15).

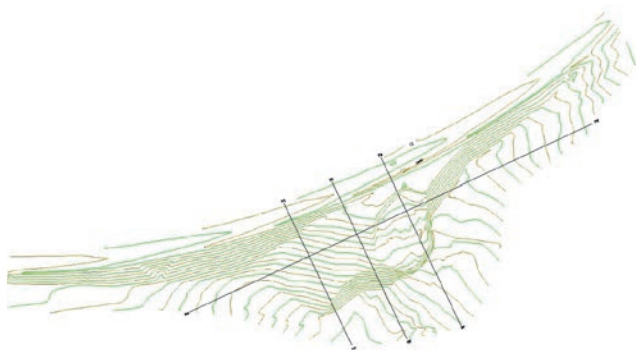

Figure 15. Doljani cutting contour lines obtained by TIN model

3.5. Advantages and deficiencies of unmanned aerial vehicles

The use of unmanned aerial vehicles presents a number of advantages the most notable being the possibility of adjustment to various needs of the users, possibility of analysing and surveying hardly accessible areas and, in case of breakdown or fall of the unmanned device, the life of the pilot is not put to danger. Some possible drawbacks are high production and maintenance costs, high costs in case of fall or breakdown of the flying device, and the fact that it can not be used in adverse weather conditions. In addition, the error in operation of the unmanned device can result in the fall which, in addition to damage to objects on the ground, can result in fatal accidents.

Good quality photogrammetric surveys can presently be made by low-budget unmanned aerial vehicles equipped with cameras. Positive features such as great flexibility with regard to accuracy of survey results, and high level of efficiency and automation, point to the selection of the photogrammetric method, which has been standardly used for a number of years. Photogrammetric survey has become accessible to a large number of users due to availability of low-budget unmanned aerial vehicles equipped with digital cameras. Although these flying devices undoubtedly have a high measuring potential, it should be noted that they have primarily been developed for recreational flight and making films, videos and photographs for personal use, without any terrain measurement aspirations. The survey using low-budget unmanned systems in sets and blocks, with the corresponding longitudinal and transverse overlapping between individual photographs, results in photographs that are subsequently processed according to photogrammetric principles, as additionally enhanced with algorithms that can take into account limitations present in low-budget unmanned aerial vehicles. The measurement can be made using the image correlation method, which enables automatic determination of homologous details in the overlap between the neighbouring photographs and, hence, a photogrammetric reconstruction. Reliability of photogrammetric measurements in the zones with a hardly distinguishable texture, such as gravels and grass, can be increased through radiometric manipulation of digital images. This results in a three-dimensional calculation model for a transport infrastructure segment and its immediate vicinity.

Figure 16. Countries participating in DESTination RAIL project and factors affecting current railway infrastructure [2-4]

Latest studies aimed at determining accuracy of the use of unmanned aerial vehicles in the large-area mapping applications, and in determining volume of soil material deposits and open cast mines, have proven to be of particular significance. Draeyer and Strecha [38] and Stretcha [39] have established that the use of unmanned aerial vehicles for measuring volume of soil material deposits is by 2-3 % more accurate compared to GNS (Global Navigation Satellite System) and 0,1 % compared to LiDAR (Light Detection and Ranging). Cryderman et al [40] have conducted similar investigations and, when measuring volume of soil material, they obtained an accuracy that is by 0.75 higher compared to GNSS. Wang et al. [41] have compared volume measurements for an open cast mine as obtained by an unmanned aerial vehicle and LiDAR, and the comparison resulted in the difference of 1,5 %.

4. Legislation on the use of unmanned aerial vehicles

When considering the use of unmanned aerial vehicles, one can not avoid the issue of legality of their use in any given area. While in most countries the use of these devices is still in a "gray" zone, some countries have clearly defined the rules and guidelines for the use of unmanned aerial vehicles, and these rules are normally set by a regulatory body, such as the Federal Aviation Administration (FAA) [42] in the USA, and the Civil Aviation Authority (CAA) [43] in Great Britain.

Aware of the need to regulate the use of unmanned aerial vehicles, Croatian Civil Aviation Agency (CCAA) [44] passed in January 2015 its draft "*Bylaw on unmanned aerial vehicle systems*", which was subsequently revised and officially

Table 2. Flight categories defined in Bylaw [23]

Class of unmanned aerial vehicle system	Class of flight area			
	I Undeveloped area	II Developed area	III Inhabited area	IV Densely inhabited area
5 OM(1) < 5 kg	A	A	B	C
25 5 ≤ OM < 25 kg	A	B	C	D
150 25 ≤ OM ≤ 150 kg	B	C	D	D
Note (1): OM - operating weight of the unmanned device				

published in the National Gazette No. 49/15 in May 2015 [45]. According to CCAA this bylaw regulates "general, technical and operative conditions for the safe use of unmanned aerial vehicles, unmanned aerial vehicle systems, and aircraft models, and conditions that have to be met by persons participating in the use of these aircrafts and systems".

Provisions of this Bylaw do not apply to unmanned aerial vehicles that can not achieve the kinetic energy of more than 79 J, where relevant speed for calculating the greatest kinetic energy to be achieved by a particular unmanned aerial vehicle, as related to its mass, is the maximum speed that can be achieved by such unmanned aerial vehicle (final speed of falling, or maximum speed of controlled flight, whichever is the greater). According to Article 3 of the Bylaw, unmanned aerial vehicles by which flying operations are conducted are divided into three classes with regard to their operative mass while, according to Article 4, flying areas are divided into four classes depending on the development of the area, population density, and presence of humans. This has served as the basis for defining flight operation categories as related to the level of risk imposed by such flight on the surrounding area (Table 2), where operative and technical requirements for the conduct of flight are set for each category.

5. Research initiatives on the use of unmanned aerial vehicles

Unmanned aerial vehicles will certainly be increasingly used in the future for various transport infrastructure applications. This has also been confirmed by the project DESTination RAIL, which is funded by the European Union in the scope of Horizon 2020 projet [46]. The project is a part of the programme "I2I Intelligent Infrastructure" that is related to the "intelligent" and "user-friendly" railway infrastructure. Fifteen partners from nine European countries, i.e. research institutions, small and medium-size enterprises, consulting companies and institutions in charge of railway operation, take part in this project. Croatia is represented on the project by Geotechnical Department of the Faculty of Civil Engineering of the University of Zagreb, as a research institution, and by HŽ Infrastruktura d.o.o. as an institution in charge of railway operation. Figure 16 shows countries participating in the implementation of the project, as well as some factors influencing railway infrastructure such as: rockfalls, landslides, earthquakes, scour of material from railway embankments, railway flooding, etc.

The basic idea of the project is to develop the so called FACT (Find – Analyse – Classify – Treat) tool that will enable persons responsible for the operation of railway infrastructure to distribute more appropriately the funding needed for the rehabilitation of such infrastructure.

The possibility of using unmanned aerial vehicles on railway infrastructure will be studied through the working group "Find", where unmanned aerial vehicles will be used in the scope of visual assessment of rail infrastructure condition, and detection of phenomena that negatively affect operation of traffic. In addition, a program will be developed to enable transformation of digital data and their direct use in computer programs for stability analyses and stress-strain analyses.

6. Conclusion

The use of unmanned aerial vehicles can greatly broaden, improve, and even fully replace traditional methods for mapping, and for determining volumes, cross sections, contour lines and other parameters that are needed for engineering analyses. Their use is especially appropriate in case of steep and high cuttings and other hardly accessible sites where implementation of traditional survey procedures can sometimes prove hazardous. Despite evident advantages of unmanned aerial vehicles, some limitations do exist with regard to deficiencies of the method itself, and the regulatory framework. In this respect, the Bylaw on unmanned aerial vehicle systems, regulating the use of unmanned aerial vehicles, has recently been enacted in Croatia. Concerning the potential the unmanned aerial vehicles have with regard to their use in various transport infrastructure applications, it is significant to note that an increasing number of projects are dealing with this topical issue. One of them is the project DESTination RAIL funded by the European Union in the scope of the Horizon 2020 programme.

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