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USE OF A LASER SCANNING SYSTEM FOR PROFESSIONAL PREPARATION AND SCENE ASSESSMENT OF FIRE RESCUE UNITS

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Review article

Abstract: The paper presents results of a study focused on usability of a 3D laser scanning system by fire rescue units during emergencies, respectively during preparations for inspection and tactical exercises. The first part of the study focuses on an applicability of a 3D scanner in relation to an accurate evaluation of a fire scene through digitization and creation of virtual walk-through of the fire scene. The second part deals with detailed documentation of access road to the place of intervention, including a simulation of the fire vehicle arrival.

Keywords: 3D documentation, fire rescue units, scene assessment, simulation, scanning.

Introduction

Brief introduction to unique and new methods of spatial digitization

There are various possibilities in using laser scanning system within the Fire Rescue Service. The principle of scanning consists in fast, automatic and accurate detection and capture of a large amount of spatial points in a tri-axle coordinate system, where each point is defined by X, Y, Z coordinates. These coordinates may be in a local or to GPS linked coordinate system. The latter are called geo-referenced and can be utilized together with digital or other available map data, such as land registry or map data of access roads. The result forms a highly accurate localization of individual points defining small and large objects, technologies, constructions, or forensic clues found within an intervention area. Such obtained data allow accurate detection of any dimensions, calculations of area, or volume of objects.

Because spatial scanning belongs to geodetic measurement methods for spatial coordinates, the results of the measuring are very accurate. Spatial data, which consist of a cloud of points are collected and recorded by a spatial scanner.

For the purposes of this article we will further reference a scanner, which was acquired by the Population Protection Institute in Bohdaneč Spa for the department investigating causes of fires in 2016. This is a 3D terrestrial laser scanner type FOCUS X130 from the American manufacturer FARO. It offers precise scanning up to the distance of 130 m and it captures everything that is within its line of sight.

To scan more complex and vast areas scanning is made from several individual posts and obtained data are then connected together into a single resultant project.

When working, the scanner is stationary mounted to a tripod. In practice, various kinds of tripods can be used; from standard 1,8 m to high-rise stands with no exception of commonly used 4,5 m stand, or special stands allowing the scanner to be ejected horizontally above or across ledge, enter the property through window, or scan the area below the standpoint via the upside down method.

The 3D scanner is contactless. It can be placed within a safe distance from any object of interest, i.e. to maintain a prescribed safe distance from the place where the leakage of hazardous substances or ongoing fire occurs or an imminent explosion threatens.

Scanner accuracy is +/- 2 mm to 25 m when scanning glossy materials such as polished chrome and stainless steel. When used conventionally, the scanner reaches an average accuracy of +/- 0.8 mm. The scanner captures 360 x 300 degrees or a user-defined segment.

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Laser monochrome beam of FARO FOCUS X130 system has a 1550 nm wavelength, thus operates in far infrared wavelength of electromagnetic radiation (Fig. 1). Primarily the 3D data are scanned in the far infrared spectrum and uncoloured. Visualized are in greyscale.

The scanner has a build internal camera in that is able to document colour information of the visible electromagnetic spectrum (Fig. 1). The resulting colour image, which when processed is applied to the 3D data, is then at a resolution of up to 70 million spatial points (70 spherical megapixels).

The scanner is equipped with additional internal sensor technology, such as already mentioned GPS, digital compass, thermometer, altimeter, digital leveller, and more. These sensors operate mostly automatically and at the time of scanning they help to complement the 3D data with other necessary information. A more detailed description of the laser scanning method the system uses was described in the conference papers Fire Protection (Marek and Nejtková, 2016).

The scanner usually works directly with the basic especially for Focus and other 3D scanners developed software. This allows the user to process and manage scan data efficiently and easily by using real time, on-site registration, automatic object recognition, scan registration and positioning and an entire overview map of the completed project generation. Project data can be published in web format and are thus accessible to anyone throw a simple web browser. The basic software is usually used for primary simple measurement, 3D virtualization and meshing as export to various point cloud and CAD formats for further processing. The range of further processing software palette is vast and target, purpose or user preference dependent. Often the software comes from different industry branch. Very helpful is suitable layout software that can easily create sections, layouts, ortophoto views and section profiles of areas of interest from a point cloud (see Fig. 10 and 11 as example). Other additional and more sophisticated software pool can be used for exact objects modelling (e.g. software designed for reverse engineering or forensic software can be used). For various simulations and virtual tours even with virtual reality outputs from simple one task up to professional filmmaking software can be used.

Fig. 1 Detail of an infrared and colour scan of a loading station with marked scanning positions (Nejtkova and Marek, 2016)

Use of a laser scanning system abroad and in firefighting practice

The method of spatial digitization is for the purposes of the Integrated Rescue System of the Czech Republic currently used only rarely and mainly in studies performed by authors of this article. However, it is used much more frequently abroad. Specialized police workplaces are being gradually formed at the regional or cantons level. Those units provide continuing service for executive units. Their main purpose is to conduct good quality, professional and rapid topographical documentation, which they provide to requesting units. With regards to the fire prevention and repression abroad this method has not yet been used.

The method supplied the authors with fast, accurate and extensive information and was used in a unique, in the domestic and foreign literature yet unpublished, way to solve the bellow described real problem of analysing of a passage of a chosen fire vehicle through a specific chemical production company.

The aim of this paper is to present a new, progressive method of spatial digitization and laser scanning in terms of its use by the Fire Rescue System in the form of application studies, which are based on real requirements, present its options, pros and cons. Another objective of this paper is to identify and describe a method for an efficient use of spatial data and lay the foundations for the implementation of these analyses for practical purposes.

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Materials and methods

Digitization and creation of virtual walk-through of the fireground scene

A. A filling station of hazardous substances

To verify applicability of the laser scanning system by fire protection units, we chose a chemical manufacturing company. After identifying a few possible areas, we chose the following objects - a chemical loading station with a tank and technology for bottling and coiling, an area in front of the loading station designed for storage of transportation barrels, and above-the-ground tanks situated in a common emergency sump. We present some possibilities of using laser scanning system in firefighting practice on these premises.

In the particular case of the loading station, we compared information received by firefighters upon their arrival at the fire scene from the firefighting documentation. According to that information the size of the loading station is 10 x 24 m and a height is 5.5 m. On the site we performed 3D scanning, subsequently created a three-dimensional model and a selected portion of the space gained by scanning and listing the standpoints into a single local project. Fig. 2 shows an example of measuring that can be performed without restrictions. The project is demonstrated with millimetre accuracy in a virtual model, which is further used to simulate possible manipulation with intervention techniques, firefighting procedures, or a method of disposal of hazardous substances. Compared to the description of construction documentation related to fighting fires we found upon our arrival that the loading station was located in the production hall with a gabled roof and an air-shaft. An open steel shed with a pent roof was built next to the hall. In the obtained model it was measured that the loading station consists of a roofed area made of steel construction with a main area of the loading station with the length of 12.57 m, width of 12.88 m, maximum internal height of 7.28 m, headroom roof is 5.05 m and 3.82 m. Adjoining steel roof extension is with the length of 3.51 m, a width of 3.51 m, headroom in the rear part is 3.23 m, and the front part of the outbuildings has reduced headroom by steel truss to 2.94 meters. The floor of the loading station was measured to have minimum slope, with the length of 12.26 m just 4.63 cm. The immense advantage of such resulting model is its accuracy and timeliness, factualness, and comprehensiveness corresponding directly with the condition at the time and place of intervention.

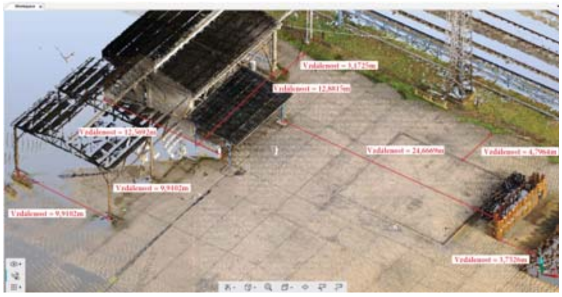

Fig. 2 3D view of the entire project with a demonstration of dimensional measurement (Nejtková and Marek, 2017)

When managing an intervention, an incident commander needs crucial information concerning storage of hazardous substances. In our case, there were uncontrolled warehouses with both full and empty transport cases and containers. The 3D scanning system is able to promptly deliver information about the sizes and exact positions of those cases and containers, of the total number of barrels and tanks. We are also able to calculate the cubage of each case and container (Fig. 3).

The system allows performing spatial modelling process as shown in Fig. 3. The scanner scans objects in direct line of sight (those data are for illustration depicted in blue), thus it is a segment of individual barrels. Created grey shaded 3D models of barrels, each with a volume of 0.221 m^3, can already be seen in the bottom row on the first and second pallet from the right. This source provides mainly information concerning a number of barrels, their exact location relative to one another, or their placement on the pallet. This information can help the incident commander to decide on the possibility of their rollover or collapse due to unstable ground, their misalignment or improper storage. It is also possible to obtain information about deformations of the barrels, either because of an impact or due to an increasing pressure during overheating of flammable liquids. The accuracy of the data is evident in the presented real deformation of the containers or on solidified magma dripping of asphalt on the road. (Fig. 4).

Fig. 3 3D models of transport containers - barrels on pallets (Nejtková and Marek, 2017)

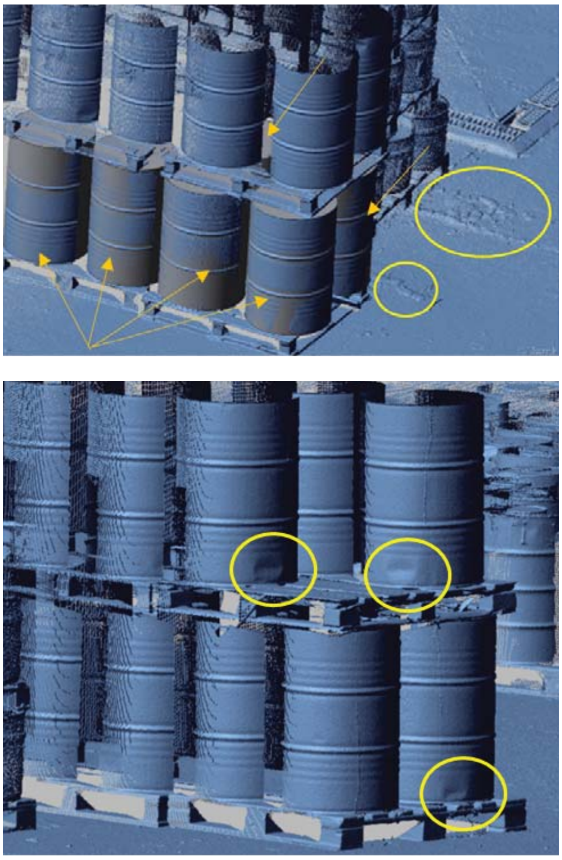

Fig. 4 View of a selected 3D part of the project with six modelled pieces of barrels containing dangerous substance and shipping containers with visibly damaged mantle (Nejtková and Marek, 2017)

B. Emergency sump

Large quantities of flammable liquids are stored in stationary reservoirs, which are located in emergency and leakage sumps. An emergency sump is used to hold leaked liquid during emergency situations and is dimensioned for at least the net volume of the largest reservoir of the technological equipment, container or a shipping case in which flammable liquids are stored, but at least for 10 % of the volume of flammable liquids drained into the sump provided that the largest reservoir has net volume at least twice that of any other container drained into the sump, or 20 % of the volume of flammable liquids drained into the reservoir in other cases (CSN, 2003). Another example of using the laser scanning system Faro FOCUS X130 was scanning the leakage sump for documentation of technical condition and calculation its real cubic content.

According to the project documentation there are four aboveground reservoirs with a volume of 150 m^3 and a radius of 3 m. By simple distance measuring using a laser range finder it is possible to determine interior dimensions of the emergency sump to be 44.46 x 11.21 x 1.05 m. To define the net volume of the emergency sump, we must subtract the concrete foundations of individual reservoirs up to the sump height. According to the measured data the volume of the emergency sump is 468.12 m^3.

Exact result of each reservoir volume is formed by a measurement of each radius. The first reservoir has a radius of 2.943 mm, the second 2966 mm, the third 2966 mm, and fourth 2990 mm. When measured precisely on a 3D model we elicited that the sump has the following dimensions: 44.48 m x 11.21 m x 1.05 m, which is 526.1 m^3 (Fig. 5). To determine an exact actual capacity of the emergency sump, it is necessary to subtract all the concrete bases of reservoirs, reservoirs themselves, as well as construction and transportation pipeline routes to the height of the sump. Such calculation is impossible to do using standard measurement methods, but thanks to the gained 3D model it is no problem to do so now. It was calculated that the actual volume that the emergency sump is able to capture is only 407.3 m^3. The difference between the distance measured precision by the rangefinder and the scanner is insignificant, but the actual volume difference of the emergency sump measured by the scanner with all obstacle objects subtraction varies by almost 60 m^3.

When comparing common measurement methods and the 3D scanning method we realized that the existing methods are inaccurate to the extent of about ten percent, which leads to the increase in assumed volume of the emergency sump comparing to the reality. This knowledge can be crucial in designing and approving of project documentation for the storage of flammable liquids, also in the preparation of the anticipated fire rescue intervention with the leakage of flammable liquid and decision-making at the time of conducting the intervention.

Fig. 5 3D view of the whole project (Nejtková and Marek, 2017)

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Fig. 6 Detailed coloured 3D image of the emergency sump (Nejtková and Marek, 2017)

Chemical production plants display characteristics of activities for which there are no standard intervention conditions. The plant operator is obliged to elaborate documentation related to fighting fires through an operating plan or card (Decree 2001). The text part of the document consists of data concerning necessary forces and means obtained through calculations, and the graphical parts shows precise deployment of reservoirs, including emergency sumps. Even in this case the laser scanning system can be applied. The system is by using multiple scans capable to accurately capture the places of each storage reservoir within the emergency sumps, their exact distances from each other and from other objects, but also their cubic contain.

Subsequently, it is possible to carry out accurate virtual measurements using acquired 3D data. As an output we obtain topographical documentation, i.e. 2D maps with a scale, orthogonal views, 2D sections and plan views. Using laser measurement, it is possible to visualize the traces, which are not normally visible to the human eye, mainly combustion traces, or forensic traces (Nejtková and Marek, 2017).

Opposite to the investor's duties Fire Rescue Service does not compile buildings fire safety and fire fighting instructions and documentation. On the other hand it is very well possible and useful to use scanned data during intervention situation solutions or exercise simulations. Particularly during professional preparations fire rescue units can meet their possible fireground perimeter and individual hi-risk objects. Using acquired scanned data they can "virtually" get to the places of intervention before any event occurs.

Generally taking one scan from a single location can take from one minute to up to 2 hours, based on the detail resolution settings. But it is reasonable to say and based on learned experience single scan usable for forensic purposes takes about 5 minutes in the exterior and about 3 to 4 minutes in the interior to obtain. In the extreme event situation, if suitable scanner location is found it is possible to set less detail resolution and after just 1 minute data can be uploaded to a laptop for processing and evaluation. Even thou this data will remain colourless and in the "greyscale" version (for fast scanning only IR distance mode will be probably activated) they will provide all objects of interest measurements, distances or terrain declination and other demanded data.

It is obviously possible to scan data during long term firefighting intervention in given time intervals even from the same place to obtain precious precise mapping of dangerous chemical spread development or other necessary fire rescue evolution documentation. For elimination in such situations constantly moving direct visibility obstacles e.g. working firemen and their equipment and engines, it is still recommended to make scans from multiple places. Especially since referencing them into one coordinate system for evaluation is not any issue.

As part of a few scanning drawbacks, it is not possible to scan objects below water or liquids surfaces. But during spreading of liquids with water like characteristics, the liquid surface and its movement will be, due to specific IR reflexion, clearly shown and thus easily possible to monitor in scans as localized dark black area.

3D space data are used as basics for virtual 3D modelling abroad. Such simulations are suitable for special pre-op preparation of fire rescue units.

Simulation

A. Introduction to conditions of deployment and demonstration of the method

In the second part of this article we targeted the suitability of spatial digitalization method and data processing in the area of virtual simulation.

In the application study we focused on the capability of driveway to possible fireground verification. Based on the Fire rescue service unit fireman working experience, (unit placed to IV. category under the 1985 Czech Republic bill of law, decree 2001b) a problematic driveway for fireground was selected. Based on fireman testimonies there are two driveways to the place of interest labelled for our purposes as C, that is direction A and from the opposite site direction B (see Fig. 7).

In this particular case the driveway is localized in a chemical industrial plant complex build early in 19^{th} century. The complex has been enlarged, rebuild and modernized during time. Access roads here lead

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through the whole compound and through individual manufacturing plants. Clear passage is made difficult by all around occurring technology lines, technology transport routings, pipelines, over road technology bridges, pillars of lighting and others.

One of the ways to be acquainted with the access roads schematics and there's capabilities is to study pre-fire and pre-incident planning documentation. Based on the 2001a decree, in the Czech Republic, the duty to elaborate such documentation falls to every hi-risk fire occurrence facility operator or operator of facility with difficult or extraordinary fire extinguishing conditions. Such documentation shows, among other, access roads and escape paths. These in formations are in text and graphical layout.

The second way to meet the fire district is using probing practice drives. This way is both timely and financially demanding for it is required to use directly fire fighting vehicles and drive it all the way. The accessibility and clearance of passages cannot be checked till the site.

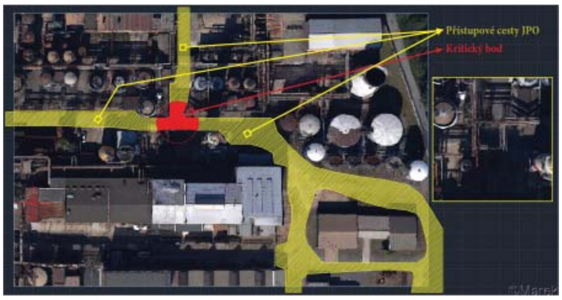

Fig. 7 Industry plant analysis - access roads in yellow, critical point in red (Marek and Nejtková, 2017)

This applied study allows researching the fire district using spatial digitalization. During pre-planning and fire protection strategy forming it is possible to make visualized simulation of a crucial passage points and determine what fire trucks and engines can reach potential places and which cannot. During that time it is possible to scan places of interest and potentially difficult access hi risk areas inside plants or city streets where fire and rescue work can be imminent. After scanning, such data can be analysed and processed to create simulation of individual fire scene task, all that using relatively low costs and low time demands. The output can be an analysis of ground accessibility or it can be directly used as trigger for documentation update and revision that falls to the facility owner obligation and responsibility. During tactical and stress testing exercise preparations such data can be used for planning, vehicles, engines and their spreading selection, access roads utilizations analysis and determinations, identifying distances form and to fixed objects and obstacles. Subsequently it is possible to verify the otter functionality of fire engines and trucks staging places.

The next step to do just once without any need to repeat is scanning of fire fighting vehicles, trucks and engines used by fire-fighters. The scanning can be done almost anywhere when the engines are not in need of use. The outcome creates fire vehicle database to import selected engines into virtual simulations space. It is practical and recommended to scan vehicles also when they are fully loaded with extinguishing agent and ready to travel to fireground, in states with maximally ejected leaders, backbones or ramps and other variations to be further included as potentially essential factors into simulations as well.

Desired scanned fire ground and fire engine or vehicles are imported to one common project after basic pre-processing. There the analysis and simulation of different events can occur.

B. Case study - driveway in an industrial plant

We scanned parts of driveway communications including critical place of passage in the selected industrial plant. This place is significant by its narrow passage profile, crossings and many vertical and horizontal technological installations as cables and tubing creating demanding obstacles for passing. On the scanning day we also received information from local plant fire department on how they pass throw the narrow profile. The truck company seemed to be only possible to drive from one way that is from B to C direction as described above. Even then they were convinced it is necessary to approach in two steps with reversing in between. The A to C passage was considered not possible to drive throw with the designated fire car.

After scanning of the location the scanning of the fire department vehicle TATRA 9000/540 designated for extinguishing flammable liquids in this plant followed.

Acquired space data was processed by urban engineering and simulation software and the following simulation was able to analyse the most optimal passage way and passage possibility in this critical area.

The result was compared with provided Fire rescue department information.

Based on acquired plant model as presented on Fig. 8, three passage directions A, B and C were mapped. For those places a rectangular Cartesian isometric views were created. These views were used to capture distances and measurements of interested objects for further analysis. After taking all necessary and relevant measurement, virtual models of fire engines were placed to the model. The analyse follows.

Fig. 8 Detailed, real and accurate spatial coloured model of entire situation (Marek and Nejtková, 2017)

Fig. 9 and 10 show coloured spatial model of fire rescue engine. This is an example of primary outcome from spatial laser digitalization. Measurements on the picture represent true real values of the vehicle, possible additional made modifications and extensions included. On Fig. 9 the total vehicle length distance includes behind the corner hidden leader extension. That is also why the dimension line is drawn behind the vehicle.

Fig. 9 Acquired true and accurate special coloured model of the fire engine with simple dimension capability example

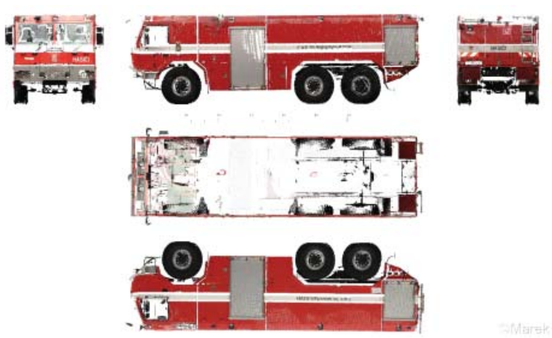

Fig. 10 Basic isometric views on the acquired special model TATRA, including scale (Marek and Nejtková, 2017)

Measurements of the real model of the plant in three sliced views A, B, C resulted in following findings:

Real net passage width from B to C is 6.14 m and lowest passage high is 4.13 m; According to the vehicle height the remaining space above it is 1.35 m.

Real net passage width from A to C is 5.34 m wide and 3.78 m high. The space above the vehicle will be 0.98 m.

All calculations are based on scanned fully load vehicle.

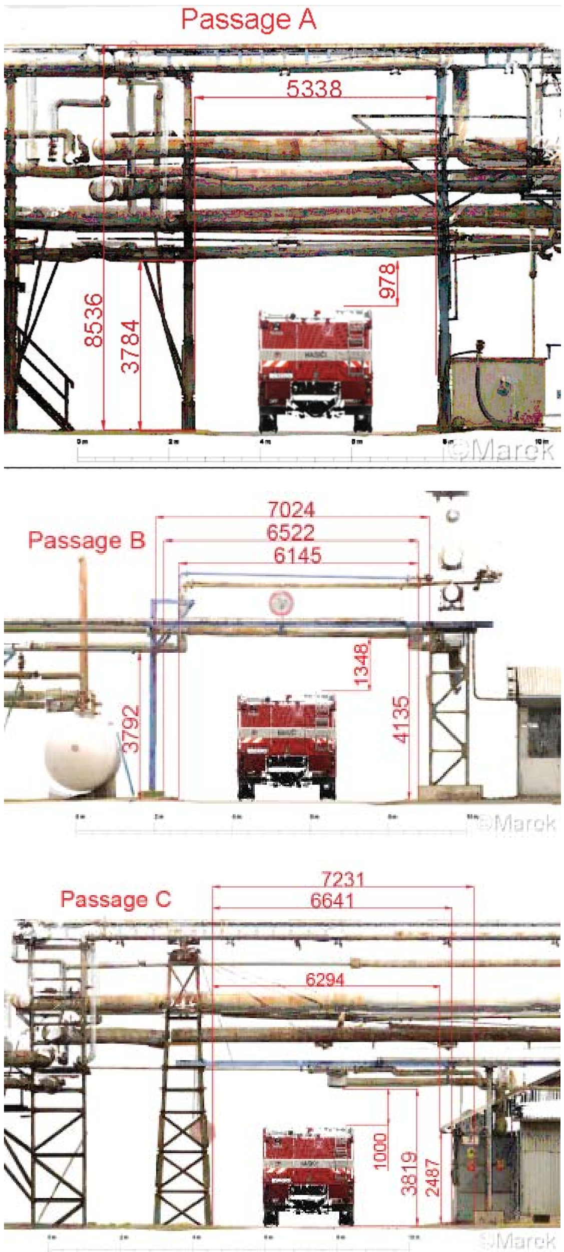

Fig. 11 Isometric view of A, B, C passages witch virtually placed vehicle including scales and metric dimensions. (Marek and Nejtková, 2017)

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After just described basic dimensional analysis we forwarded to simulations of vehicle passage. The analysis was made for passage from A to C and from B to C directions as shown and labelled above.

The simulation was first made for idealized model based on prescribed outside contour (wall to wall) turning radius given by the Czech standard for all fireworks vehicles within given S weight class (CSN EN 1846, 2014), marked as model A. Secondly the simulation was also made to involve turning radius skid correction resulting from vehicle mainly to rear axle load, non-zero speed of the vehicle, weather and road conditions and other non-theoretical factors. In such situation the idealized minimum turning radius is not achievable, the car moves more in a spiral way. This second model option is marked as B.

For better presentation the top isometric view was chosen. This shows the entire scene. All obstacles are highlighted in a green colour. Distances of vehicle to those objects obtained from the simulation are also marked.

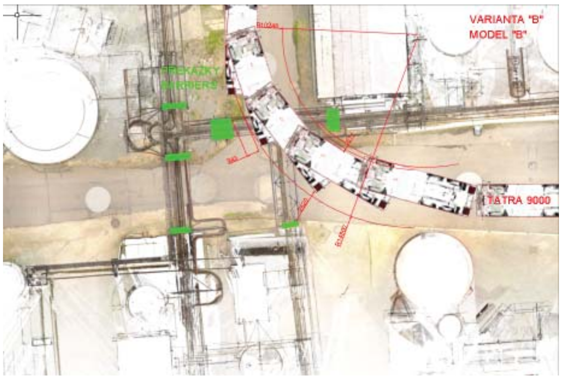

Fig. 12 Fire engine passage simulation outcome: Variation passage B to C, model B including at least minimum skid correction by load, speed and weather like conditions (Marek and Nejtková, 2017)

Fig. 13 Fire engine passage simulation outcome: Variation passage A to C, model A with no skid or trace correction (Marek and Nejtková, 2017)

Fig. 12 shows the simulation outcome with the corresponding skid calculation. The vehicle speed remains very slow, but the model is more accurate and realistic. The Fig. 13 shows only the theoretical turning radius and as presented, even without any radius corrections the passage without reversing is not possible.

The given fact is even with the skid calculation larger turning radius the maximum allowable vehicle speed for passing remains very low. This can be supported by comparing the measured radius with the turning radius of 120 m recommended by Czech standard (CSN EN 1846, 2014) for road construction for 20 km.h^{-1} speed.

The performed simulations brought entirely new information, that using all available space and with low speed of the vehicle the given selected fire engine should be able to pass throw this low profile plant driveway section from B to C direction even without reversing. Implementation of the correct passage trace may after the verification during the pre-planning practise drives bring significant manoeuvre simplification and drive range time shortening.

For the A to C direction is the situation different. The turning radius available does not offer additional reserve space to perform the turning manoeuvre without reversing. Not mentioning the needed additional skid space for realistic turning. In this case the premise of impossibility of fluent passage given by the fire department truck company was confirmed.

It is essential to say that the possibility of passage throw narrowed points like this has two more factors. That is the ability of the driver to follow exact path and the spare distances to critical object and or the nature of those objects. The manoeuvrability of heavy class cars is not as easy and precise as a simulation. Thus it is badly necessary to account those factors into any simulation outcomes and conclusions should also count for real world feedback.

Results

This article showed, described and verified the spatial digitalization method benefits using practical examples and experience. Since various measurements and studies were made, most of the results is already captured in the text above.

This described method allows precise, fast and detailed documentation of real or potential firegrounds. The relevant scene can be flammable or dangerous component storage, fire debris place, vehicle fire, etc. The laser scanner is capable of scanning of almost every object from a far safe distance and without interfering with ground forces (Ministry of Interior, 2004).

Authors tested the usability of the scanner in practical examples fire fighting units can face, as dangerous compounds elimination pre-ops and new methods of studying fire department grounds.

The article showed there is a great potential of digital laser spatial scanner usability. It can be used in pre-incident planning, pre-fire operation or during on ground decision making. As presented with suitable software the analyses work can bring useful results far beyond simple measurement.

The authors scanned several fire-fighting vehicles and stared a new spatial database of fire-fighting vehicles and engines. They developed and optimized specific way of special data processing.

Conclusion

Undeniable positives of this method are precise, factual, complete and objective spatial documentation as vast data source. Working with 3D spatial data brings more realistic and truthful situation and place description. Stored data include information from both visible colour and infrared spectrum. Compared to other commonly used methods of documentation as is for example traditional photography, it is the able to receive measuring data even in poor lighting conditions, at night or at dark environments.

Based on the 3D data structure and the spatial completeness it is possible to perform different analyses for different projects without the necessity of re-scanning or re-photographing missing data on site that may after short passed time no longer exist or is forensically corrupted. On the other hand the scanned data can be always amended of additional related spaces. Thus the scanning can be done by segments. Time-space comparisons are other offered possibility of utilization.

The semiautomatic and most used scanned data outcomes are isometric views, floor layouts, sections and slices. This data give unlimited distance volumes areas, inclinations and deviations measurement options. Such data are swiftly available and directly usable by incident commander for incident decisions and after the event intervention for evaluations. The native data can be made accessible to users without any specialized software by virtual tours, simulations, videos and by publishing web-explores.

Negatives of this technique are slightly higher initial hardware and software costs and the requirement for faster and more powerful computing devices suitable for vast data processing. Processing of complex analyses and virtual tours as the more advanced level output is significantly more human and processing time consuming than simple analyses provided on the scene.

Limitations of the system come only from its parameters described above, but it is safe to say the system has sufficient range, resolution and speed. Some may see the limitation of the system on terrestrial (usually from up to 4 m height tripod) scanning and not reaching top views of higher buildings and objects. For that a different technology (i.e. drones filming) exist today. The important thing is, that the video no scale data can be merged with precise terrestrial 3D point cloud measurements to form unified view, making those self-standing technologies complete each other.

Limitation for larger usage of 3D data benefits is the shortage of trained and experienced operators with knowledge for various CAD/CAM, modelling, post-processing and simulation software that are needed for quality 3D data outcome. There is also little to none education or training for firefighting and public safety recruits in the area of 3D data usage or processing. And technical engineers from other disciplines specializing to 3D data processing area do not look for employment in fire department or public safety and service sectors very often.

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