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Abstract:
The aim of this study was the verification of unmanned aerial system (UAS) application in vehicle swept path analyses by analysing the advantages and disadvantages and comparing field test results with two software solutions. In this study, swept-path analyses were performed for two vehicle types and two turning angles. UAS images were used to extract the vehicle swept path and the results were compared with two commonly used swept-path analysis software. The results indicated larger deviations between the swept paths for an angle of 125° for a light truck. For both analysed vehicles and turning angles, larger deviations were observed for the outermost point trajectory. Passenger cars occupy less space performing 125° turns than software analysis predicts, indicating that they are on the safe side when designing vehicle manipulative surfaces. For the analysed light truck, a larger turning radius was observed than the predicted for a 125° turning angle, which may be caused by the approaching and turning speeds under which the test was performed. Finally, while the UAS recording process is relatively simple and fast, data processing is demanding and time-consuming. To fulfil its full potential within swept path analyses, UAS needs to be complemented by proper data analysis software solutions for faster and more accurate swept path extraction, which would improve and rationalise the traffic area designing process.

Keywords:
UAS; swept path; traffic area design; vehicle trajectories

1 Introduction

The basic concept of unmanned aerial systems (UAS) was introduced and first developed by military engineering. The history of unmanned aerial vehicles (UAV) goes back to ancient Chinese civilisation, who used to intimidate their enemies with balloons going on hot air heated by oil lamps [1]. Later, the same technique was used by the Austrians to attack Venice using unmanned balloons stuffed with explosives [2]. The two main features of today's commercial unmanned aerial systems (UASs) are the quadcopter configuration and the radio guidance (control) systems. The quadcopter configuration technology was introduced in 1907 by the Bréguet brothers and Charles Richet. A radio guidance system was developed by Archibald Low, and it was used by pilotless military drones during World War I. However, early radio-controlled aircraft could only be operated within the visual sight of the controlling pilot, and Edward M. Sorensen was the pioneer who patented a ground terminal used to track aircraft movements.

Today, according to the valid EU legislative defined by Directive 2019/945 [3], UAS is defined as a system consistent with unmanned aircraft (UA), i.e., any aircraft operating or designed to operate autonomously or to be piloted remotely without a pilot on board, and remote control equipment (any instrument, equipment, mechanism, apparatus, appurtenance, software, or accessory that is necessary for the safe operation of a UA other than a part and which is not carried on board that UA). In the past, UASs were primarily used for military purposes; today, their use is widespread across all spheres of life. In particular, its application in environmental monitoring of dangerous or polluted locations, eliminating workers' potential health threats, is prominent. UASs were used for remote sensing data collection to evaluate the environmental impacts of the Vihovici coal mine (which is being used as a landfill, and the effects of the mine on the water quality in the Neretva River [4].

In civil engineering, new technologies such as UASs can notably improve construction processes by increasing quality and security, reducing costs, and facilitating decision-making processes. In [5], the UASs applications within the transportation domain are divided into three areas: road safety (accident investigation, risk assessment, and road network surveillance); traffic monitoring (improved traffic flow analysis methods based on data collected from UASs); and highway infrastructure management (bridge inspection and monitoring and pavement distress recognition). The UAS can be used to precisely extract distances between vehicles to determine the relationship between different parameters of traffic flow [5]. In [6] UAS dataset was used for road pavement distress detection and analyses, allowing quick identification of the presence of distress and pavement conditions; therefore, critical areas could be identified for a more detailed analysis. This is mainly because the UAS collected data must be improved so that the severity of the distress can also be determined and analysed [7, 8].

One of the prominent advantages of the UAS for its application in road construction is the eye-view angle of the camera, which allows the extraction of vehicle trajectories with high accuracy. Its increasing popularity is also a result of its low cost, high resolution, good flexibility, and wide spatial coverage [9]. From UAS image records, it is possible to obtain data on vehicle type, position, velocity, and trajectory under mixed traffic conditions using computer vision and image processing techniques [10]. In addition to vehicle trajectory, for proper intersections, horizontal curves, and parking areas, design swept path analyses are the main concerns. Turning vehicles occupy more space than straight-moving vehicles, and much more manoeuvring space is required because the front wheels turn, and the rear wheels do not follow their trajectory. The swept path of a turning vehicle (Figure 1) is an envelope swept out by the most prominent points of the vehicle body (the outermost point is the vehicle's left-side front overhang and the innermost point is the right-side rear axle).

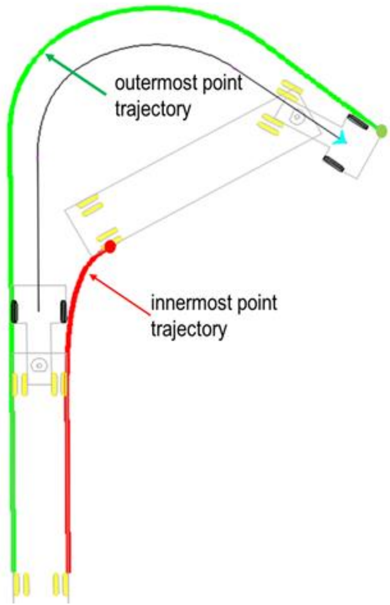


Figure 1. Vehicle swept path

Turning behaviour is one of the most challenging driving manoeuvres, and the geometry of the vehicle's path depends on the steering speed, the speed of the vehicle itself, and the lateral distance between the exit point and the curb (i.e. choice of exit lane) [11-13]. Today, swept path analysis is performed using specialised swept path analysis software such as AutoTURN (Transoft Solution), Autopath (CGS Labs) or Vehicle Tracking (Autodesk) which usually run on the AutoCAD interface. Swept-path analyses using software are easy and user-friendly; however, their accuracy and comparison of different software solutions are of concern. Field measurement is the most accurate method for determining vehicle trajectories and swept path analyses, as well as for verifying the reliability of the software used; However, this technique is time-consuming (conducting actual tests and later data processing), organizationally demanding, and expensive [14]. In field tests, the Global Navigational Satellite System (GNSS) was used as a simplified, less time-consuming, and less expensive method, yielding results comparable to software solutions [15].
The primary goal of this study was to gain preliminary results and experience with UAS applications for swept-path analyses to improve intersection, roundabout, and parking area design processes. The aim and scope of this research was to identify the main advantages and disadvantages of using a UAS for vehicle swept path analyses and to compare the obtained results with two frequently used software design solutions. With this aim, a comparison between two software solutions is presented (AutoTURN and Autopath), along with test field measurements.

2 Research methods

Previous research has shown that using UAS for surveys is reliable, with average deviations in terms of the total station method of less than 6 cm [16]. Therefore, in this study [17], the scope was to use UAS records for vehicle swept-path analyses. For the purpose of this research, two types of vehicles were selected (Figure 2): a passenger car (PC-length 4,57 m; wheelbase 2,65 m) and a light truck (LT-length 9,4 m; wheelbase 4,82 m) because of the easy availability of test vehicles. Furthermore, heavy vehicles are usually used for similar analyses, and to the best of the authors' knowledge, there is no swept path analysis for cars. However, knowing this is essential for the design of parking areas within highly urbanised residential areas, such as garages, because of the limited available space in most design projects.

Figure 2. Field test vehicles

The test was carried out at the Osijek-Čepin airfield, where the test site was created by a geodetic survey using the Global Positioning System (GPS) method and cones. All processed images for swept path analyses were positioned with regard to a point marked outside the test site as a georeferenced point. Vehicles moved at the predetermined speed throughout the test site, averaging 15 km/h up until the yellow marked line (speed start line). Cones were used to mark the path that the vehicle had to follow (which was easily noticeable to the driver) using the maximum steering angle. Three polygon passes were recorded for two turning angles (90° and 125°) for both vehicles. The test site is shown in Figure 3.
Recordings were taken using a UAS Phantom 2 Vision+ equipped with a 14MP camera to obtain photogrammetric images. Two images were analysed every second. Two swept path analyses software were used for verification and comparison of the results: AutoTURN (Transoft Solution) and Autopath (CGS Labs) using vehicles of the same sizes (Figure 4).

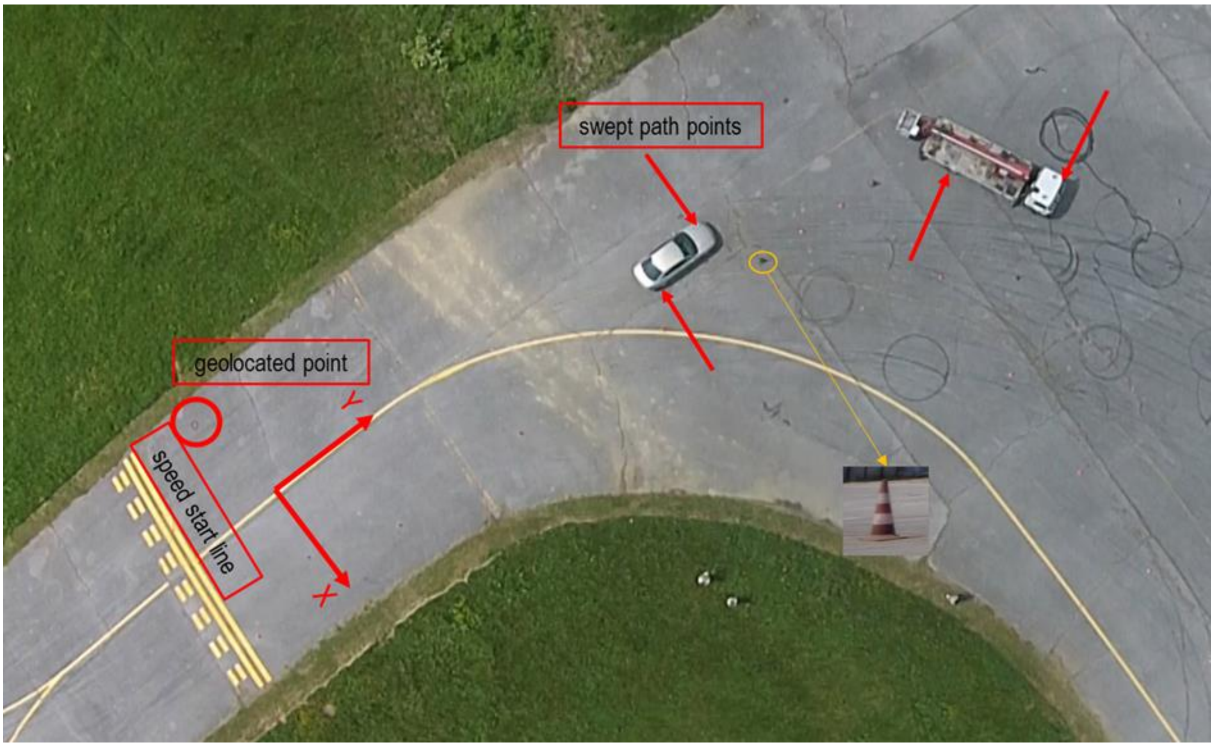
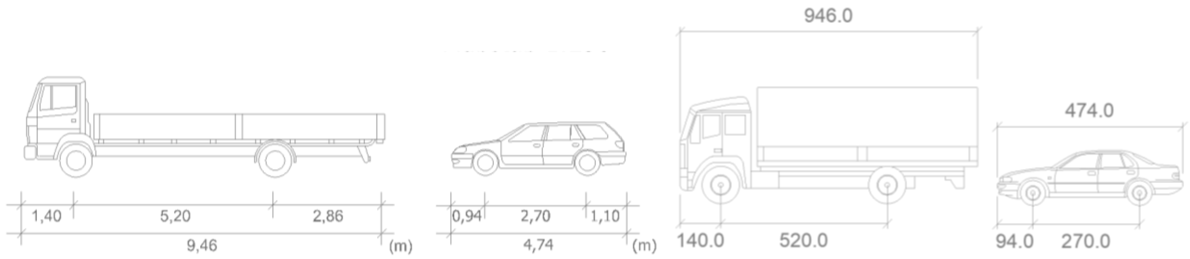


Figure 3. Test site



a) b)

Figure 4. Autopath (a) and AutoTURN (b) vehicles included into analyses

3 Results and discussion

The preliminary results are presented in Table 1. and Figure 5. The UAS swept path is presented as the average trajectory of the innermost and outermost points of three vehicle passes for each vehicle and the turning angle.

Table 1. Mean value and standard deviation (in parenthesis) of divergence between swept path determined by UAS, Autopath and AutoTURN

Vehicle	Angle (°)	UAS vs Autopath		UAS vs AutoTURN		Autopath vs AutoTURN	
		outermost point (m)	innermost point (m)	outermost point (m)	innermost point (m)	outermost point (m)	innermost point (m)
PC	90	0,21 (0,15)	0,12 (0,13)	0,66 (0,45)	0,21 (0,12)	0,72 (0,45)	0,50 (0,27)
	125	0,62 (0,73)	0,31 (0,24)	0,54 (0,47)	0,29 (0,24)	0,13 (0,25)	0,12 (0,15)
LT	90	0,27 (0,17)	0,14 (0,09)	0,58 (0,64)	0,25 (0,17)	0,59 (0,59)	0,26 (0,17)
	125	0,77 (0,79)	0,63 (0,64)	0,97 (0,71)	0,83 (0,74)	0,47 (0,38)	0,20 (0,17)

According to the results presented in Table 1. and Figure 5., regardless of the type of the vehicle, larger deviations between swept paths were recorded at an angle of 125°. In addition, for both the analysed vehicles and turning angles, larger deviations were observed for the outermost point of the trajectory. When comparing the swept paths from the UAS and software solutions, a higher divergence was observed for the AutoTURN software for both vehicles and turning angles (Figure 5). It is interesting to note the difference between the two software swept paths; there is a significant divergence, particularly in the outermost point trajectory, which is more pronounced for a 90° turning angle (Table 1). By comparing the UAS results, it can be concluded that passenger cars occupy less space when performing 125° turns than any analysed software predicts, so the analysed software solutions are on the side of safety when designing manipulative surfaces. However, for the analysed light truck, a larger turning radius was observed compared to the predicted radius for a 125° turning angle. This may be because of the approaching and turning speeds under which the test was performed (15 km/h), because offtacking is known to be highly correlated with the travel speed [13]. Instead of dynamic horizontal analyses with predefined or direct manual control of the vehicle at the selected speed, turning templates are used for software analyses as a fast and simple procedure for design purposes. The reason for the recorded deviations also lies in the difference in the dimensions and values of the steering lock of the test vehicle and models used by software, such as a human factor, that is, driver characteristic influence on test results, which should be considered in further research.

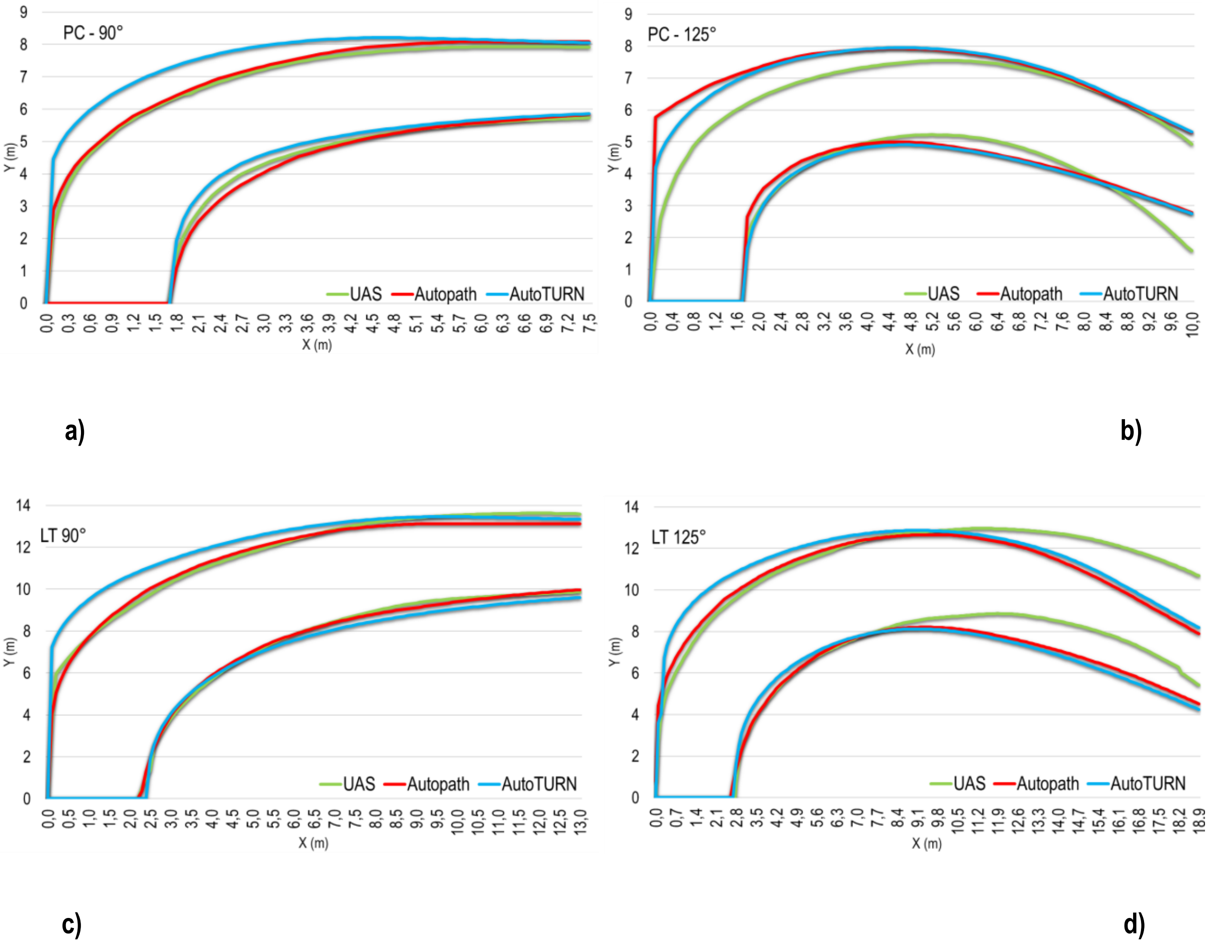


Figure 5. Swept path analyses comparison for a passenger car (a and b) and a light truck (c and d)

The use of software solutions is an easy, fast, and user-friendly method of conducting swept path analyses, which is required for proper intersection, roundabout, and parking area design. The majority of the software solutions are based on vehicle dimensions and the steering lock angle. However, because it is a time-consuming and expensive process, there is limited data on exact swept path analyses performed in real environmental conditions using real vehicles on a test site. UAS can be used for traffic monitoring in existing traffic areas such as intersections or parking areas, and within this research an attempt was made for swept-path extraction from such records. Although the recording process itself is relatively simple in terms of organisation and time consumption, the data processing itself is quite difficult and the accuracy depends on the recording resolution, among other well-known UAS monitoring limitations, such as weather conditions and recording obstacles such as buildings and vegetation on site. The main advantage of the UAS is real-time vehicle trajectory monitoring, possibly for multiple vehicles and turning angles simultaneously. To fulfil its full potential within swept path analyses, UAS needs to be complemented by proper data analysis software solutions for faster and more accurate swept path extraction, which would improve and rationalise the traffic area design process.

4 Conclusions

In this study, an attempt was made to use UAS images for vehicle swept path analyses with a critical review of the advantages and disadvantages of this method. The following conclusions were drawn.

- There is a noticeable difference in outermost point trajectory comparing all three used methods.
- For higher turning angles, higher divergence between the used swept-path templates and the UAS image extracted templates are recorded.
- There is potential for using UAS records for swept-path analyses, but image processing procedures need to be improved and automated.

The results and conclusions are drawn from the research conducted on a limited number of tests, which include a limited number of test drives, vehicles, and turning angles. In the future, more tests should be conducted.

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References

[1] College of Earth and Mineral Sciences, Department of Geography. Geospatial Application of Unmanned Aerial System (UAS). Accessed: 25.2.2022. Available at: https://www.e-education.psu.edu/geog892/node/643

[2] Vyas, K. A. Brief History of Drones: The Remote Controlled Unmanned Aerial Vehicles (UAVs). 2020. Accessed: 25.2.2022. Available at: https://interestingengineering.com/a-brief-history-of-drones-the-remote-controlled-unmanned-aerial-vehicles-uavs

[3] Official Journal of the European Union L152. Commission delegated regulation (EU) 2019/945 on unmanned aircraft systems and on third-country operators of unmanned aircraft systems. 2019.

[4] Mikulić, I.; Nuić, M. Possibilities of using earth observation for analysing the environmental impacts of former coal mine in Vihovici. *Advances in Civil and Architectural Engineering*, 2016, 7(12), pp. 46-56. https://doi.org/10.13167/2016.12.6

[5] Ahmed, A. et al. On the fundamental diagram and driving behavior modeling of heterogeneous traffic flow using UAV-based data. *Transportation Research Part A: Policy and Practice*, 2021, 148, pp. 100-115. https://doi.org/10.1016/j.tra.2021.03.001

[6] Inzerillo, L.; Mino, G. D.; Roberts, R. Image-based 3D reconstruction using traditional and UAV datasets for analysis of road pavement distress. *Automation in Construction*, 2018, 96, pp. 457-469. https://doi.org/10.1016/j.autcon.2018.10.010

[7] Zhu, J. et al. Pavement distress detection using convolutional neural networks with images captured via UAV. *Automation in Construction*, 2022, 133, https://doi.org/10.1016/j.autcon.2021.103991

[8] Biçici, S.; Zeybek, M. An approach for the automated extraction of road surface distress from a UAV-derived point cloud. *Automation in Construction*, 2021, 122, https://doi.org/10.1016/j.autcon.2020.103475

[9] Chen, X. et al. High-resolution vehicle trajectory extraction and denoising from aerial videos. *IEEE Transactions on Intelligent Transportation Systems*, 2021, 22(5), pp. 3190 -3202. https://doi.org/10.1109/TITS.2020.3003782

[10] Chen, A. Y. et al. Conflict analytics through the vehicle safety space in mixed traffc flows using UAV image sequences. *Transportation Research Part C*, 2020, 119, https://doi.org/10.1016/j.trc.2020.102744

[11] Abdeljaber, O.; Younis, A.; Alhajyaseen, W. Analysis of the trajectories of left-turning vehicles at signalized intersections. In: *Transportation Research Procedia*, Ulengin, F et al. (eds.). 26-30 May 2019, World Conference on Transport Research – WCTR 2019, Mumbai, India: Elsevier; 2020. pp. 1288-1295, https://doi.org/10.1016/j.trpro.2020.08.152

[12] Ma, Z.; Sun, J.; Wang, Y. A two-dimensional simulation model for modelling turning vehicles at mixed-flow intersections. *Transportation Research Part C: Emerging Technologies*, 2017, 75, pp. 103-119. https://doi.org/10.1016/j.trc.2016.12.005

[13] Gkoutzini, A. et al. The speed factor in swept path analysis. In: *6th International Conference on Road and Rail Infrastructure*, Lakušić, S. (ed.) 20.-21. May 2021. Zagreb, Croatia, Department of Transportation, Faculty of Civil Engineering, University of Zagreb; 2021. pp. 483-489.

[14] Stančerić, I. et al. Road widening in curves according to Croatian regulations, German guidelines and computer simulation of vehicle movement. In: *6th International Conference on Road and Rail Infrastructure CETRA 2020*, Lakušić, S. (ed.) 20.-21. May 2021. Zagreb, Croatia, Department of Transportation, Faculty of Civil Engineering, University of Zagreb; 2021. pp. 475-482.

[15] Džambas, T. et al. Reliability of vehicle movement simulation results in roundabout design procedure based on the rules of design vehicle movement geometry, In: *6th International Conference on Road and Rail Infrastructure CETRA 2020*, Lakušić, S. (ed.) 20.-21. May 2021. Zagreb, Croatia, Department of Transportation, Faculty of Civil Engineering, University of Zagreb; 2021. pp. 507-515.

[16] Moser, V. et al. Comparison of different survey methods data accuracy for road design and construction, In: *4th International Conference on Road and Rail Infrastructure - CETRA 2016*, Lakušić, S. (ed.) 23.-25. May 2016. Šibenik, Croatia, Department of Transportation, Faculty of Civil Engineering, University of Zagreb; 2016. pp. 847-852.

[17] Ravlić, K. *Analiza geometrije kretanja vozila primjenom bespilotne letjelice*. [master thesis], Josip Juraj Strossmayer University of Osijek, Faculty of Civil Engineering and Architecture Osijek, Osijek, Croatia, 2017. [In Croatian]