Acta Avionica
Volume XXVI, 50 – No.1, 2024, DOI: 10.35116/aa.2024.0002

RISKS OF MULTIPATH SIGNAL PROPAGATION FROM GPS SATELLITES IN MOUNTAINOUS AREAS DURING THE USE OF UAV AS SUPPLEMENTARY DEVICE FOR HEMS OR SAR

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Abstract. It cannot be disputed that using unmanned aerial vehicles as a supplementary search and rescue component is still increasingly being discussed. Several approaches to solving the problem can be stated - buying specially designed unmanned aerial vehicles for HEMS (Helicopter Emergency Medical Service)/SAR (Search and Rescue) or modifying conventional UAVs to supplementary devices for HEMS or SAR. Regardless of which alternative the end-user prefers, the navigation method and determining the current position in space stays unchanged - primarily, the navigation signals from GNSS (Global Navigation Satellite Systems) satellites are used. However, this method can be loaded by the error caused by environmental conditions in which the rescue UAV moves, such as mountains, valleys, specific flora, trees, and much more. All of that causes attenuation, loss or multipath propagation of the signal. In the case of the remote-controlled flight of the UAV (by a pilot-operator or operator itself from the ground station) and when the rule of direct visibility (Visual Line of Sight - VLOS) is used for an unmanned aerial vehicle, this may not be a considerable problem. However, during an automated or fully autonomous flight and the flight of an unmanned aerial vehicle beyond direct visibility (Beyond Visual Line of Sight - BVLOS), knowledge about the exact position of the UAV in space is crucial. The presented article is dedicated to verifying the claim about the significance of the problem of multipath signal propagation from the GPS (Global Positioning System) satellite in a selected mountain area, The Little Cold Valley in High Tatras, Slovak Republic.

Keywords: Beyond Visual Line of Sight; Global Positioning System; multipath; Visual Line of Sight; unmanned aerial vehicle

1. INTRODUCTION

The flights of unmanned aerial vehicles depend on the information they receive from external sources, such as remote-control information from the ground station and from the pilot-operator or autonomous flights whose trajectory and flight mission are pre-programmed in advance [1,2]. Adherence to the predefined flight trajectory is checked and corrected by sensors onboard implemented into the unmanned aerial vehicle (for example, ultrasonic or radar "scanning" of the surrounding environment) or by receiving and evaluation elements designed to receive and process information about the current position in space, from the GNSS receiving device, which enters as correction information to the built-in INS (Inertial Navigation System) unit [3,4]. Based on the above, the relevant determination of the current position in three-dimensional space is crucial for the flights of UAVs, especially in locations that are difficult in terms of their natural effects - mountainous areas, lowlands, valleys, areas with dense forest cover or, on the contrary, urban built-up areas [5-7].

The principle of the position determination function using GPS satellite navigation systems is well known to both professional and lay readers. The use of at least four signals from four successfully and reliably caught satellites located in an ideal constellation above the receiving device (ideally offset by 90°) to comply with the rule of solving four equations for determining the pseudo-distance with four unknowns (coordinates [x, y, z] and time correction δ_t), are well-known primary conditions of satellite navigation. The GPS can be used as a standard positioning system, with carrier frequency L1 (1575.42 MHz) or a precise positioning system, with carrier frequency L2 (1227.60 MHz) [8].

The navigation systems that use the space segment, satellites, are laden with specific errors, which significantly affect the possibility and reliability of using navigation information obtained in such a way. The standard positioning accuracy of the GPS is ±15 m without using augmentation systems like EGNOS or WAAS; when an augmentation system is used, an accuracy of approximately ±2.5m can be achieved. Therefore, it is understandable that any additive error (for example, caused by the environment or atmosphere) reduces the reliability and accuracy of positioning on the order of several meters. The error rate of positioning increases not only for the GPS navigation system itself but also for other systems that regard satellite navigation signals as their correction input, as is standard in the case of the INS system [8-10].

Significant sources of error are the effects of the ionosphere (estimated error ±5 m, varies during the day), displacement of the orbit on which the satellite is located (estimated error ±2.5 m), time synchronization error (estimated error rate ±2 m), multipath signal propagation (estimated error rate ±1 m), calculation errors (estimated error rate ±1 m) or influence of the troposphere (estimated error rate ±0.5 m). The Selective Availability (SA) error, i.e. an intentionally introduced error on the L1 carrier frequency, which until May 2000 made positioning in space for civilian users inaccurate by tens of meters, is still incorrectly delighted among the errors affecting positioning using GPS. On the contrary, the importance of the correct constellation of the four captured and used satellites above the receiving device is still underestimated. In the case of an incorrect constellation of satellites, inaccurate triangulation occurs - the area in which the three imaginary circles (signals from the captured satellites) intersect is vast, and an error in determining the position can be more than 150 m [8-10].

Of all the documented errors, one error is specific and closely related to the environment in which information from GPS satellites is used – it is a multipath propagation error (error leads to dysfunctionality of the use of navigation information from the tuned GPS satellite). It is precisely the multipath propagation error that can be well-modelled and simulated directly for the local area/environment in which navigation information from the GPS satellite system is planned to be used. In our research, it is the local area of the Little Cold Valley in the High Tatras, where the use of supplementary unmanned aerial vehicles for the needs of SAR and HEMS is assumed [8].

The remaining errors in the positioning accuracy of the GPS, which cannot be directly specified for the given area, are considered in the positioning process, and their correction takes place directly when calculating the position in the receiving device. This is accomplished with the help of a standardized model of the ionosphere or troposphere, as well as more precise time correction calculations.

Since the use of unmanned vehicles as supplementary devices for HEMS and SAR is increasingly common, especially in hard-to-reach mountain areas, there was a requirement to simulate partial locations where multipath signal propagation can occur. It is mainly to gain awareness of areas in which navigational information from GPS satellites may be distorted due to multipath signal propagation in the predefined test corridor, reserved for remote-controlled but also fully autonomous flights of supplementary unmanned aerial vehicles for HEMS or SAR purposes.

2. MULTIPATH PROPAGATION OF THE GPS NAVIGATION SIGNAL

Multipath signal propagation occurs when a radio signal (electromagnetic wave) transmitted from the GPS satellite is reflected from the surrounding environment and surfaces. In urban development, these are mainly buildings (glass infills, windows, roofs); in nature, they are mainly rocks, cliffs, trees/forests, marshes, lakes, tarns or large river flows. Unwanted reflections and the resulting multipath propagation of the signal occur due to the typically conical emission of the electromagnetic wave (signal). For this reason, if there are reflective surfaces near the receiving device, the signal transmitted from the GPS satellite is received by the antenna of the receiving device not only directly but also indirectly. The path that the indirect, i.e. reflected, signal must travel is longer than it should be in the case of a non-reflected (correct) signal [9]. Due to this, a greater pseudo-distance to the captured satellite is measured than it should actually be. This error causes an increase in the inaccuracy of determining the position in three-dimensional space up to a few meters. In the case of mountain flights, even these "small" errors can cause significant complications in navigating to the point of interest (the nearness of rocks or trees is often less than a few centimetres, so errors up to a few meters can be fatal).

2.1. Options leading to a decrease in GPS error caused by the multipath signal propagation

The general principle states that areas, where multipath signal propagation does not occur, should be preferred. Unfortunately, this cannot be realized during UAV flights in mountainous areas. A suitable modification of the receiving GPS antenna element is considered in such a case; by way of illustration, the placement of a protective "dish" under the antenna element can significantly reduce the receive of the reflected signal from rocks, cliffs, lakes, rivers, or from the ground. However, this method is not applicable to every unmanned or manned aircraft, just as the success of reducing such signals may not be the same for every application. Technical modification or improvement of the receiving device for receiving and processing signals from GPS satellites is also considered, but this solution is time-consuming and relatively expensive [10].

All options for reducing the multipath propagation error are united by one crucial thing - a suitable solution should ideally be applied only after testing a specific receiving device in the selected area in which its application is intended. The following chapters and subchapters of the article are dedicated to simulating flights in a determined area of the Little Cold Valley in the High Tatras and to the local influence of multipath signal propagation from GPS satellites in areas where the navigation signal transmitted from the satellites is partially or eventually entirely dismissed or is dangerously propagated by multipath way.

2.2. The base conditions for MATLAB modelling and simulation of the multipath propagation of the GPS navigation signal

The basis of any modelling is to define the primary input conditions - not only in terms of programming. It is important to take into account available information, studies or statistics, and subsequently design analysis and the overall strategy for problem-solving.

The first step is to accurately define the researched, so-called determined area of interest/simulation and implement a specific, highly accurate map of the selected area, gained by the Elevation API function, into the simulation environment (MATLAB). The presented research is focused on the local area of the Little Cold Valley in the High Tatras (Fig. 1.).

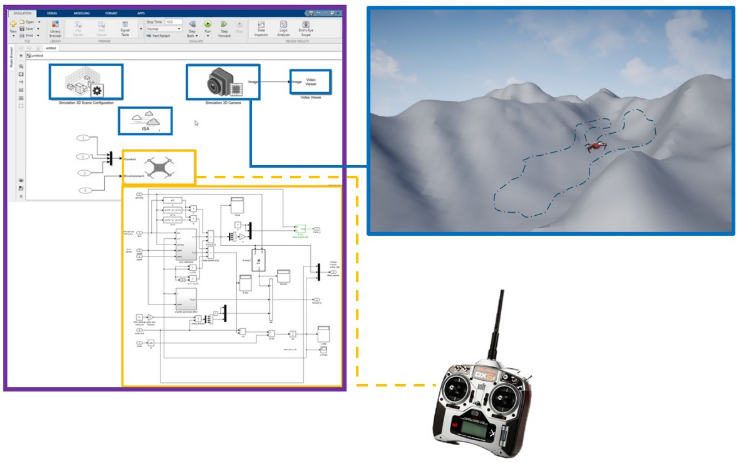

Figure 1 The illustration of the simulation workspace with the 3D model of the High Tatras mountains

This relatively huge area is well-known for local areas with complete loss of the navigational signal from GPS/GNSS satellites and with local areas with significant multipath propagation of these satellite navigation signals. It is caused mainly by the small distance from the rocks and cliffs, the high level of forestation and the area through which the Cold Creek flows, which creates the main flow of The Giant waterfall [11]. All the mentioned aspects create an ideal high-reflection surface for unwanted signal reflection, and thus, its multipath propagation must be considered in real and simulation conditions.

The second step is to choose the exact receiving device or module that will be used for real and simulated flights. In the presented case, a receiving module was chosen for receiving and processing signals from GPS satellites, supplied by default as a certified part of the onboard equipment of the DJI Mavic Pro UAV [12]. The manufacturer provided all the specifics of the given module to the researchers by agreement. However, the manufacturer strictly prohibits sharing this data. For this reason, it is not described in detail in the technical specifications of this article.

During the evaluation of the error rate, i.e. the multipath propagation of the GPS signal, the basic premise of evaluating the position using GPS satellites is taken into account [13]. All signals that are not captured by the GPS receiving device directly from the satellite, i.e. under VLOS (visual line-of-sight) conditions, can be considered as reflected and their propagation as multipath – the path from the satellite to the receiving device is indirect, and the propagation time is extended. Each signal transmitted by the GPS satellite contains an imaginary transmission time stamp, which the receiving device's precise clock uses to calculate the pseudo-range between the captured GPS satellite and the receiving device (UAV) [8, 14, 15]. For this reason, any signal propagating indirectly will cause an incorrect calculation and, thus, the determination of the pseudo-distance. Such a pseudo-distance is always longer than the real pseudo-distance measured under VLOS conditions and increases the inaccuracy of the measurement and, thus, the determination of the current position in three-dimensional space.

3. EVALUATION OF THE SIMULATION RESULTS OF THE MULTIPATH PROPAGATION OF THE GPS NAVIGATION SIGNAL IN THE DETERMINED AREA OF THE LITTLE COLD VALLEY IN THE HIGH TATRAS

The most reliable way to define the degree of degradation of the GPS signal in a determined area due to multipath propagation is, in the first step, to generate the visibility of GPS satellites (each satellite has a number, so-called ID), within 24 hours from the start of the simulation and the corresponding time when the given satellite will be visible above the given area (Fig. 2.).

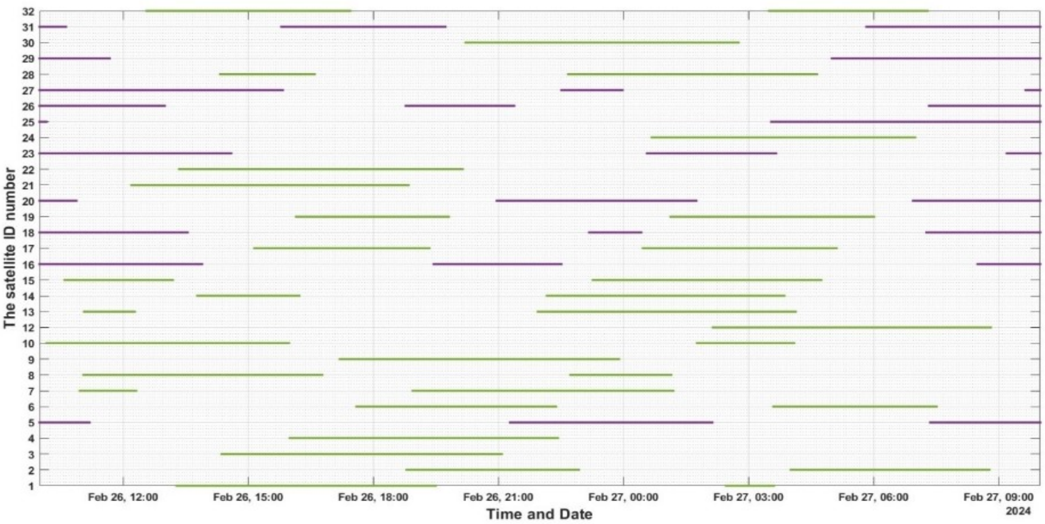

Figure 2 Visibility of all GPS satellites above determined local area - The Little Cold Valley, High Tatras, during the simulation experiment

All the simulations that were made out and the results of which will be presented were carried out during one day, specifically during two hours (from 10:00 a.m. to 12:00 p.m. - purple colour in Fig. 2

and Fig. 3), and were related to the precisely delineated selected area of the Little Cold Valley. The current constellation of GPS satellites at the time of the simulation is shown in the following figure (Fig. 3.). Thanks to the short period, the obtained results can be relevantly interpreted and evaluated since there was no significant shift in the constellation of satellites in orbits above the given receiving device flying in the pre-defined corridor.

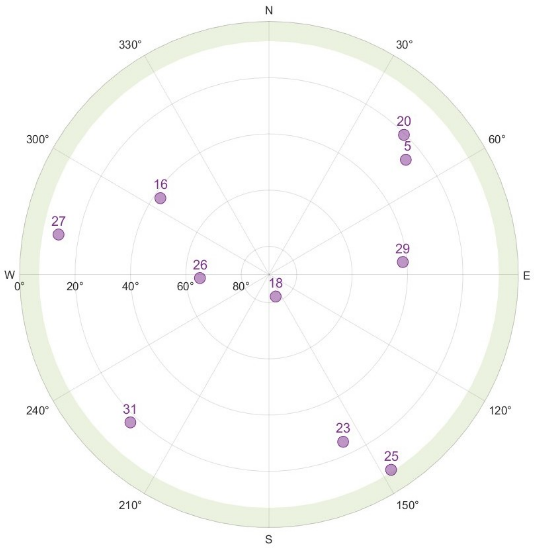

Figure 3 The actual constellation of usable and reliable GPS satellites above Little Cold Valley during the simulation experiment

The total number of visible satellites over a determined location never fell below eight - this means that under ideal conditions and the propagation of the signal from the GPS satellite to the receiving device (UAV), at least four satellites would always be detectable, which could ensure sufficient coverage and reliable satellite navigation (Fig. 4.). During the simulations, i.e. in the time range from 10:00 a.m. until 12:00 p.m. the number of visible satellites was even ten (Fig. 3. and Fig. 4.).

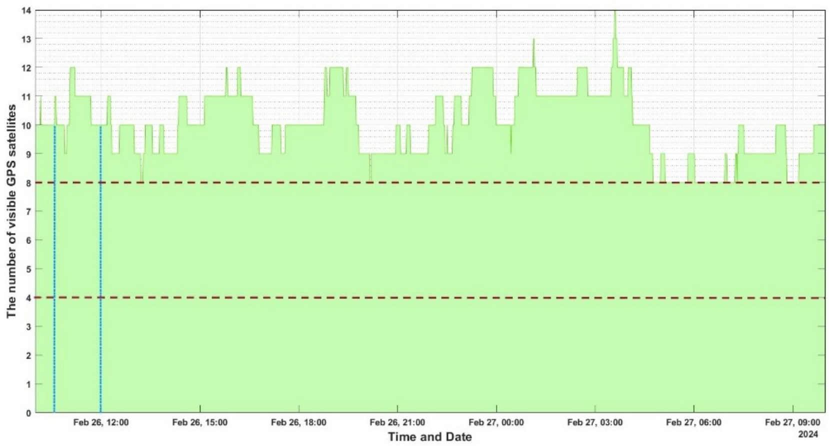

Figure 4 The number of GPS satellites visible above determined local area - The Little Cold Valley, High Tatras, during the simulation experiment

Knowing the ID of the visible satellites (Fig. 2.) and their exact constellation above the horizon of a determined area (thanks to knowing their distribution on orbits - Fig. 3) made it possible to create a simulation experiment. This experiment included specific satellites and aimed to monitor the rate and influence of multipath signal propagation from GPS satellites in the determined area, the Little Cold Valley (Fig. 5.). As already mentioned, the determined area of the experiment is known for its mountainous, rocky and forested terrain with the water-level, in which unwanted reflections of the electromagnetic signal occur.

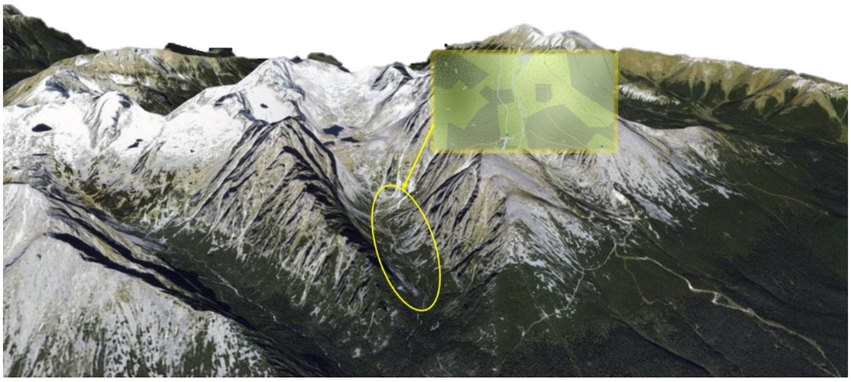

Figure 5 The Little Cold Valley - 3D map and detail of the contour map of the determined local area (around Zamkovského chalet and The Giant waterfall)

By implementing a three-dimensional map of the determined area into the simulation process in the Matlab environment, it was possible to perform a very accurate simulation of the presence of multipath signal propagation in the selected area. The previously statistically collected data, which represent the motivation for the explanation of the need to create a simulation and verification of their veracity, pointed to the fact that the area of the Little Cold Valley is characterized by areas with a failure of the navigation signal from GPS satellites and areas in which the signal cannot be captured at all - as causalities are assumed to be environmental influences and possible imperfections in the receiving equipment (GPS module implemented onboard the UAV).

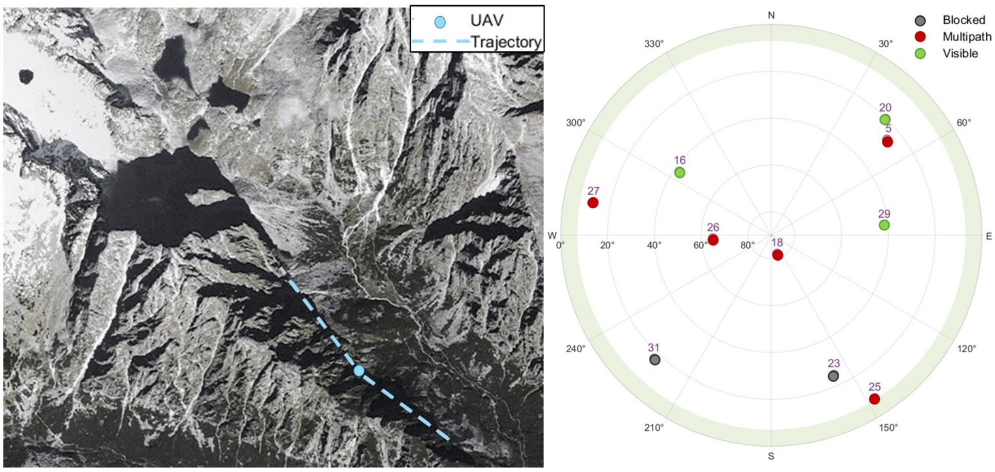

Figure 6 The results of the simulation of multipath GPS signal propagation in the local area of the Little Cold Valley

As showed the results of the simulation (Fig. 6.), although up to ten GPS satellites were visible over the determined and researched area, five of them were burdened by the multipath propagation error and thus did not provide the receiving device with correct information about the pseudo-distance of the captured GPS satellite and thus made it impossible to determine the current position of the unmanned aerial vehicle receiving navigation signal during the simulated flight in the pre-defined corridor. Two satellites were blocked during the simulation experiment, which can be explained by the influence of the mountain massif, which made it impossible to ensure the VLOS condition of the receiving device (UAV) and the GPS satellite. The remaining three satellites, whose signals were not burdened by the multipath propagation error and provided correct information about the pseudo-distance between the receiving device (UAV) and the GPS satellite, were not sufficient to create correct navigation information and thus did not allow the flight of the unmanned aerial vehicle, which used as only navigation information source GPS satellites. The simulation experiment was repeated five more times to verify the acquired results. The experiments were executed on different days and times but still had the same results. The number of affected GPS satellites by multipath signal propagation was too high in the local area, burdening at least half of the visible GPS satellites in each repeated simulation experiment. The visibility of usually two to three GPS satellites, whose signals the receiving device implemented onboard the UAV could rely on, was insufficient to meet the minimum requirement, which expresses the need to capture at least four GPS satellites to perform correct navigation.

4. CONCLUSION

Flights of unmanned aerial vehicles, mainly those intended for searching and rescuing people in hard-to-reach terrain, are accompanied by many difficulties [16, 17]. It is not only about the design aspects that these supplementary devices must satisfy - reliability, durability, sufficient payload capacity, and excellent controllability by the pilot-operator or the autonomous control software because reliable remote and autonomous control are crucial aspects for the successful performance of the flight mission.

One of the systems that autonomous controlling relies on is the GPS satellite navigation system. This satellite navigation system, operating independently or in coordination with the inertial navigation system (INS), enables the determination of the current position in three-dimensional space in any weather conditions or time of day. The exception may be local areas where signal propagation errors may occur. Undoubtedly, the error of multipath signal propagation, to which the presented article is focused, can be classified here too. This error occurs, as mentioned, especially in built-up urban areas or areas with significant environmental influence, such as high mountain massifs, forests or lakes. In these challenging environmental conditions, UAVs are used as supplementary devices for HEMS/SAR.

The simulation experiments presented in the article were performed in the pre-determined local area of ongoing research focused on the flights of supplementary unmanned aerial vehicles for HEMS, specifically in the Little Cold Valley in the High Tatras.

The accomplished simulation experiments confirmed the relevance of previously collected statistical data, which described areas in the determined location of the Little Cold Valley in which there are outages of navigation signals from GPS satellites or their complete loss. By repeating the simulation experiment several times, it was proven that the chosen area of the flight mission of the UAV (with a module for receiving signals from GPS satellites onboard) occurs either complete blocking of signal receiving from captured and currently visible satellites in the given area or caused multipath propagation of their signal, which makes it impossible to consider it as relevant. The visibility and reliable receiving of the signal from an average of two to three GPS satellites is insufficient for reliable satellite navigation. Therefore, it can be stated that in a determined local area, alternative ways of navigating UAVs must be used, and it is impossible to rely only on navigation information from GPS satellites.

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Acknowledgement:

The work of N.G. and M.Č. was supported by the following project: KEGA 033TUKE-4/2023—Virtual Complex of Aircraft and Helicopter Systems as a Means of Supporting the Teaching of Avionics Subjects.

Received 04, 2024, accepted 05, 2024