Prospects for the Use of Unmanned Ground Vehicles in Artillery Survey

Jan Ivan[a], Michal Sustr[b], Ondřej Pekar[c] and Ladislav Potuzak[d]
Fire Support Department, University of Defence, Kounicova 65, Brno, Czech Republic

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Abstract: The article deals with the currently realized research of a new survey vehicle of the Czech field artillery, which task will be support of the activity of autonomous and non-autonomous artillery weapon systems. The article describes the basic aspects of artillery survey together with the current progress of the project. Baseline for the article is description of current status of Czech artillery survey and the way it supports the artillery operations. The individual chapters then present the identified variants of the functionality of the gun navigation system and the resulting requirements for the capability of the unmanned artillery survey vehicle. Main focus of the article is to present specific approach which Czech armed forces have in terms of artillery use under degraded and GPS denied operations. All these proposals are presented according to current status of Czech artillery which transitions from non-autonomous 152mm howitzers to the new, NATO standard 155mm autonomous weapon systems.

1 INTRODUCTION

The use of artillery is evolving in time as well as development of new technologies, which helps the artillery to operate rapidly, independently and thus efficiently. Although technological development is rapid and use of state of the art technology is very common these days, basics for artillery operations remains the same. These basic are ballistic aspects, calculation of firing data and many others. One of the key basics is the use of topography and geodesy in positioning and aiming artillery pieces.

Since the Czech artillery is currently switching from non-autonomous to autonomous guns, research team from the University of defence is currently working on development of new approach to conduct of artillery survey, which should be based on unnmanned vehicles and use for surveying firing positions of both gun types as well as for mortars.

2 NAVIGATION OF ARTILLERY PIECES

It should be stated right at the beginning why topography and geodesy are considered so crucial for artillery. Unlike some other military branches, artillery, for its activity, requires precisely determined coordinates of individual artillery system emplacement (sensors and effectors or other systems) as well as key directions from individual pieces (such as gun to target lines or observer to target lines). This informations are primary used for purpose of artillery fire control to calculate firing data or fire corrections. These data are connected and interdependent and thus fire support cannot be provided without it.

At the aspect of navigation, it is currently possible to distinguish two types of artillery weapon systems – guns that have a built-in navigation system and guns that do not have it. Weapon systems that have a built-in some form of navigation system are referred to as autonomous and guns that do not have this system as non-autonomous. In this context, it is necessary to

[a] https://orcid.org/0000-0002-6194-8482
[b] https://orcid.org/0000-0002-7342-7641
[c] https://orcid.org/0000-0003-3907-6865
[d] https://orcid.org/0000-0002-0213-717X

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perceive the difference in the notion of autonomous and non-autonomous. In general, the notion of autonomy in vehicles is associated with the absence of the human element that controls the device. In the case of artillery weapon systems and their navigation system, autonomy is meant in relation to the need for external conduction of artillery survey, which assists in the navigation of the gun.

2.1 Non-autonomous Artillery Weapon Systems

As already mentioned, the non-autonomous artillery weapons do not have a navigation system and are thus dependent on the conduction of the artillery survey and preparation of fire positions where the non-autonomous artillery weapons can conduct fire.

Preparation of firing positions, from the point of view of TG (topographical-geodetic) connection for non-autonomous weapon systems, consists of:

- determination and connection of base piece fire emplacement and it´s orientation directions;
- determination of emplacement and orientation directions to platoon commanders;
- determination and connection of other guns firing positions;
- determination of site angle.

TG connection means, in the technical terminology of artillery, "*determination of coordinates and altitudes of points and determination of orientation directions*." (NN 22 01 01, 2020). Orientation directions from gun fire emplacement allow non-autonomous artillery weapons to aim at the target.

Except of the main tasks of the artillery survey units, consisting of TG connection, these units also perform other tasks. These include in particular:

- specification and reconnaissance of the artillery position area;
- specification and reconnaissance of command posts emplacement area;
- specification and reconnaissance of logistics and medical support units emplacement area;
- specification and reconnaissance of units movement axes;
- detection of radiation, chemical and biological situation;
- detection of enemy mines;
- detection of the enemy activity or presence of civilian inhabitants.

These activities conduct artillery survey units equipped with necessary technical assets to complete all of these tasks.

Based on the mentioned, it is now obvious that the tasks of artillery survey units are broad and cover both the navigation survey as well as reconnaissance and assessment of the areas.

2.2 Autonomous Artillery Weapon Systems

Artillery autonomous weapon systems (as well as sensors) are currently considered a standard type of artillery weapons within NATO. Since these guns are autonomous, they do not require conduction of artillery survey in terms of navigation. These types of land vehicles are equipped with navigation systems in the form of inertial units supplemented by satellite navigation receivers and (or) vehicle motion sensors. The assembly of these instruments allows them to determine precisely the coordinates of their current position and the directions in which the barrel (in the case of weapon systems) or reconnaissance device (in the case of target acquisition systems) is aiming.

This capability has the significant advantage because based on its capabilities it is not necessary to carry out the preparation of fire positions (reconnaissance posts), which results in:

- reduction of the risk of disclosure of individual firing positions;
- reduction of the time required to prepare artillery fire;
- reduction of human and material requirements;
- much greater autonomy in the activity of artillery and target acquisition units.

The problem is that the autonomous navigation capability of weapons and target acquisition systems suggests there is no need of artillery survey units anymore. However, it is clear that even with maximum functionality of the navigation system, there is still a need to conduct a survey of movement axes and emplacement areas.

Nonetheless, it is more important to support the function of the autonomous navigation system in the case of degradation of its capabilities, whether it is a deliberate degradation by the opponent or a degradation caused by a malfunction. When the system is degraded for whatever reason, the guns must have an alternative means to be able to aim and conduct fire. These supplementary methods mean providing navigation points to guns (sensors) to support accuracy of navigation systems or in the overall execution of the preparation of fire positions (observation posts) in the same form as for non-autonomous guns. However, both these backup techniques cannot be realized without artillery survey

units, which have the ability to eliminate these failures of the navigation system and maintain the ability of the artillery and target acquisition units to operate in any environment and under any conditions. The availability of artillery survey units is thus crucial, even when the army is equipped with autonomous guns.

2.3 Role of Artillery Survey

Currently, all weapon systems of the Czech Army artillery are non-autonomous and require the conduction of artillery survey. In 2021 a new, autonomous gun in the standardized caliber of NATO 155mm (155mm SpG CEASAR 8x8 CZ) was purchased, which will significantly change the approaches to the conduction of artillery survey (see chapter 3).

Despite the implementation of an autonomous weapon system, the Czech Armed Forces will also have non-autonomous types of systems in the form of mortars in the range of calibers 60/81/120 mm. The implementation of artillery survey will have to be preserved, however, with a fundamental change in the form of the execution of this type of activity, which will have to be modified in favour of newly acquired 155 mm SpG CAESAR.

It is necessary to mention the fact, that the Czech Armed Forces and their effort to preserve artillery survey units is relatively unique across the NATO armies. Many countries rely exclusively on the capabilities of the weapon navigation system, which they assess as reliable and does not prepare for the possibilities of backup function. Other option includes the preservation of only reconnaissance capability of artillery survey units, which could perform broad reconnaissance of axes and areas and which would not have the ability to prepare positions areas for artillery.

The effort of the Czech Armed Forces, however, is to preserve the ability to support the activity of the guns even in the case of operations in the GNSS (Global Navigation Satellite System) degraded environment and thus maintain the ability of complete preparation of firing positions. This requirement applies not only to artillery survey, but also to other domain such as the backup ability to determine the firing data in case of failure of the artillery automated fire control system.

Effort to preserve the ability to conduct artillery survey and further development of its implementation in favor of autonomous systems have currently intersected with the obsolescence of the equipment of artillery survey units. Thus, within the framework of development of artillery survey units, there is currently project being conducted aimed on the development of a new survey vehicle and setting up the overall concept of artillery survey. This project focuses on each level of command and estimate procedures to efficient support the activity of both self-propelled artillery and mortar batteries. At the same time, it deals the support of mortar batteries of special forces, which have specific requirements resulting from the nature of their activities.

3 PROCESS OF DEVELOPMENT OF ARTILERY SURVEY

The research team from the Department of Fire Support of the University of Defence was tasked with the project to develop the artillery survey capability and update its conduction to the conditions of the current battlefield and of the Czech Armed Forces artillery equipment. The objectives of the project are in particular:

1) analyse the current approach to conducting of artillery survey;
2) analyse the way of conducting artillery survey in selected countries of the world;
3) analyse the variants of the functionality of autonomous gun navigation systems;
4) analyse the specific needs of conducting artillery survey in special forces units;
5) analyse the modern technologies facilitating the conducting of artillery survey;
6) analyse the opportunities to increase the capability of artillery survey units by means of modern technologies;
7) propose a comprehensive concept of conducting artillery survey within artillery battalions;
8) propose a technical solution for a new vehicle for artillery survey units;
9) propose a possible technical solution of unmanned survey vehicle.

The main output of the research project will be a proposal of a technical solution of a new survey vehicle. This vehicle must allow raealization of artillery survey in favour of both autonomous and non-autonomous artillery systems. Additional output will be a proposal of implementation of unmanned systems, which would work particularly in favour of special forces mortar units.

In this article, the present progress and the achieved outputs of the project will be described. These outputs will relate in particular to the lessons

learned from the analysis of the current status (Objectives 1-2). In addition, a description of possible variants of the functionality of the autonomous navigation systems and the outputs of conducting artillery survey in favour of small special forces units will be provided. The main part will be Chapter 4, within which the basic requirements for an unmanned vehicle will be defined.

3.1 Analytical Outputs

Currently in Czech army, conducting artillery survey is set according to the actual weapon systems, which are non-autonomous and their navigation abilities relate to the time of their creation. The major role in conducting artillery survey lies on the vehicle UAZ-452T. This vehicle is already a considerably obsolete type of technology, whose usability corresponds to the time of its creation. Abilities and usability of equipment of this vehicle was analyzed in the project and evaluated in purpose of development of new survey vehicle.

The UAZ-452T was introduced at a time when satellite navigation systems were not available and it was built to help survey team to accurately connect fire positions for artillery units to conduct fire. Thus, the basis of this vehicle is an inertial navigation unit connected to protractor device. With this inertial unit the vehicle operator could accurately determine the coordinates of the vehicle together with directions to the designated points. Survey units were able to perform described activities without external inputs of satellite navigation. For this reason it is possible to see a parallel with the conditions of operation in GNSS degraded environment, where the signal from satellite navigation will not be available as well. The basic principle of the UAZ-452T vehicle activity was an initialization of the navigation unit above the point with precisely determined coordinates (comparison of the coordinate above the geodesic point).

Although a satellite navigation systems are currently available, it is essential that the newly developed vehicle has alternatives that allow to determine the exact coordinates and directions from each points without using satellite systems, i.e. similar to UAZ-452T (Ivan and Potužák and Šotnar, 2019).

In addition to the TG connection, the UAZ-452T allows carrying additional material, which can be used by survey units to prepare the areas of fire positions.

An important lesson from the analysis of the present situation is that the current procedures do not work with variants of the activity in favour of autonomous systems, because they were not implemented at the time of the introduction of the UAZ-452T vehicle. Therefore, it is necessary in the next step of the research project to analyse procedures of autonomous systems, which will define partial requirements on conducting artillery survey.

The findings from the analysis of the current way of conducting artillery survey are as follows:

- the vehicle UAZ-452T with its capabilities allows to perform the tasks of artillery survey in favor of non-autonomous guns. However, due to its age and technical limitations must be replaced;
- the new survey vehicle shall be built on a similar but upgraded basis to the UAZ-452T, i.e. equipped with an inertial navigation unit to perform tasks in GNSS degraded operation environment;
- The new survey vehicle must be capable of performing tasks to support the operation of both non-autonomous and, in particular, autonomous artillery systems at all levels of functionality.

The main objective of the research project is to create a new survey vehicle, which will serve as a replacement of the currently used UAZ-452T vehicle. The new type of vehicle must cover the capabilities of all types of currently and prospectively introduced weapon systems, which will be both autonomous and non-autonomous.

However, the partial output of the project is also an evaluation of the possibilities of application of modern technologies and the use of unmanned platforms for conducting artillery survey. The next chapters of this article describe the current knowledge of the project solutions – i.e. the definition of variants of the functionality of the gun navigation system. Design of both the crew and unmanned vehicle will be based on this knowledge. Further, the chapter describes the requirements for unmanned vehicle according to the identified variants of the functionality of the navigation system of autonomous guns.

3.2 Variants of the Gun Navigation System Functionality

The following step in the realization of the research project was the identification of possible variants of the functionality of the gun (sensor) navigation system. When determining variants of the functionality of the navigation system, the scenario method was used, while variants of the functionality were created for navigation systems based on an

Table 1: Variants of gun navigation system functionality and survey tasks.

Variants	Gun navigation	Survey tasks		
V_1	INS/GPS	Maneuver axes (roads) survey	Survey control points creation	-
V_2	INS			-
V_3	INS			Keeping own INS accurate
V_4	Externally			Complete firing position preparation

inertial navigation unit supplemented by a satellite navigation receiver (INS/GPS) or vehicle motion sensor (Table 1). Navigation units based on these devices represent the absolute standard of equipment of modern military equipment.

Following functionality variants for the INS/GPS navigation units were identified by scenario method:

1) maximum functionality of INS/GPS unit;
2) GPS receiver malfunction;
3) satellite navigation unavailability;
4) complete failure of the gun navigation system.

3.2.1 Maximum Functionality of INS/GPS

The maximum functionality of the navigation system is defined as the sole use of satellite navigation (GPS receiver) for gun navigation, which is continuously refining the inertial navigation unit (INS). The gun is thus completely independent and does not need additional support from survey units for its navigation.

With the maximum functionality of the gun navigation system, the survey units will perform two basic tasks – the reconnaissance of maneuever axes (areas) and the creation of navigation control points as a backup in case of failure of satellite navigation. These control points would be used to refine the inertial navigation unit by comparison of coordinates in case of satellite navigation unavailability (functionality variant 2).

3.2.2 GPS Receiver Malfunction

When the GPS receiver is not working, the navigation of the guns depends exclusively on the INS, which must be periodically refined by other means to ensure its accuracy and thus the accuracy of the artillery fire. For these cases, it is necessary that there are enough control points in the area with precisely defined coordinates (and optimally directions to landmarks) by which the inertial navigation unit can be refined.

This functionality variant does not change the requirements for the capability of the survey vehicle, since the navigation control points must be created at full functionality (functionality variant 1). The only difference is that these navigation points are actually used. Thus, the survey units perform the same tasks in this variant as in the full functionality variant of the navigation unit (functionality variant 1), i.e. they reconnoitre the manuever axes (areas) and create the navigation control points.

3.2.3 Satellite Navigation Unavailability

The unavailability of the GPS signal is situation where both gun and survey units navigation capabilities are degradedd. The reason behind is that primary navigation system of a new survey vehicle is assumed to be based on the same navigation systems as for the guns, i.e. INS/GPS.

This situation may (and it is predicted to be the most likely situation) be caused by interference with satellite navigation, or the destruction of satellites. In this case, the navigation of the guns goes again exclusively to the inertial navigation unit, which has to be refined to ensure accuracy of the navigation system (equivalent of functionality variant 2). However, a partial problem occurs with survey units, which also have to refine the INS of their navigation unit. This can be done by comparing data with already created navigation, trigonometric or geodetic points.

Thus, the survey units will still conduct tasks as in the case of functionality of variants 1 and 2, i.e. primarily to create control navigation points for the guns and to conduct reconnaissance of manuever axes and areas. However, during this activity, they must continuously refine their own navigation unit so that the points determined by them are created in the required accuracy. Although the general tasks conducted by survey units will remain the same, there will be an increase in the requirements of their activity to preserve the required accuracy of navigation data.

3.2.4 Complete Failure of the Gun Navigation System

This is the situation of a complete gun navigation system failure and no navigation data from the INS/GPS system is available. The basic variable here is the character of the gun deployment - whether it operates together with the unit or the individual gun operate separately. In the case of the gun deployment together with the unit in one fire position, it is possible to take position data form the gun next to. However, reduced accuracy should be expected and accepted.

In terms of the probability of a complete failure of the gun navigation system, this failure is most likely in one cannon, while the failure of the navigation system in all cannons of the unit is not very likely. However, when this situation occur, survey units must be equipped to conduct full preparation of artillery position area (Němec and others, 2021).

3.3 Analytical Conclusions

Analysis of the conduction of survey and variants of the functionality of the gun navigation system revealed that the most common task of survey units for autonomous gun would be the reconnaissance of maneuver axes (areas) and the creation of navigation points. These navigation points will help the inertial navigation unit to reamin accurate in case of malfunction. Another task is the ability to fully prepare firing positions in case of a total failure of the weapons navigation system.

However, in terms of frequency of use, the main tasks performed will be the creation of navigation points. The ground survey vehicle platforms must be adequately equipped for these tasks.

4 REQUIREMENTS ON FUTURE SURVEY VEHICLE

The analytical outputs clearly showed the main tasks of artillery survey units, which will be performed in favour of prospectively implemented weapon systems. Followed requirements for the survey vehicle were defined based on the identified tasks.

One of the main theses that the research team included in the project solution was the possibility of creating a unmanned survey vehicle. After analysing the current technical possibilities and solutions of unmanned ground vehicles (UGV) available on the market, it was found that UGV would be the most applicable for conducting the reconnaissance of maneuver axes and areas. Creation of navigation control points, which is another main task of survey units, cannot be realized with the current technical possibilities and further development of technologies will be necessary.

4.1 Unmanned Survey Vehicle Requirements

As already mentioned, the realisation of the reconnaissance of maneuver axes and areas will be the most frequent and at the same time the most suitable task for the unmanned survey vehicle. The defined requirements for the capability of the vehicle have been divided into the survey of maneuver axes and the survey of position areas for artillery (firing positions).

4.1.1 Survey of Maneuver Axes

Survey of maneuver axis is crucial in the framework of artillery survey to verify the patency of all paths on which artillery units can move (Rybanský and Rada and Dohnal, 2021). Movements are decisive factor for artillery units especially because of maintaining the range to provide fire support and also because of their own survivability, in terms of counter-battery fire (Kompan and Hrnčiar, 2022).

In the survey of maneuver axes are evaluated:

- dimensions of paths (width and clearance height);
- load capacity of paths;
- dimensions of bridges;
- load capacity of bridges;
- impassable places;
- risky places (glens etc.);
- mine hazard;
- infestation of weapons of mass destruction;
- others.

For the maneuver axis survey, the vehicle shall be equipped with an assembly of sensor and other sensing systems to enable the abovementioned tasks to be accomplished. The essential requirements for the maneuver axis survey unmanned vehicle have been defined as follows (the vehicle should have):

1) INS/GPS navigation system;
2) software tracking application within which it will be possible to plan the movement route;
3) optoelectronic system allowing real-time image recording and transmission;
4) distribution-communication device;
5) penetrometer to survey the load capacity of the soil;
6) soil mine detection system;
7) use of weapons of mass destruction detection system;
8) driving range of at least 100 km.

4.1.2 Area Survey

Areas survey for firing units is conducted with the aim of identifying and evaluating areas of firing positions and preliminary areas. The importance of this task is equivalent to maneuver axes survey. The main attributes of firing positions are open terrain, which must be bearable for artillery equipment and

must allow rapid manoeuvre in and out of these areas (existence of in and out paths). In contrast, preliminary areas are determined where conditions allow concealing the equipment.

In addition the areas must also be prepared in the form of TG connection of key points. However, this preparation is realized only for non-autonomous guns or in cases when the navigation system fails completely and it is not possible for the autonomous guns to distribute navigation data from other guns.

As mentioned before, the UGVs are considered only for conducting area and axis reconnaissance because TG connection of key points is a very complex matter and its implementation using unmanned vehicles would be eventual realized in the second step of the development of survey vehicles.

Following factors are evaluated within the scope of the area survey:

- dimensions of areas;
- possible locations of firing units or individual artillery systems;
- surface and soil structure;
- paths in and out of area;
- possibilities of concealment;
- etc.

Survey of areas is as crucial as survey of maneuver axis and thus the unmanned vehicle shall be equipped with designated means. On the positive side, all technical means used in the survey of axes are applicable in the survey of areas.

In addition to the systems referred to in Chapter 4.1.1, it is necessary for the unmanned survey vehicle to be equipped with a ground surveillance radar which could partially detect the presence of vehicles, persons and small unmanned aerial platforms (Nohel and Zahradníček and Flasar and Rak, 2021).

However, the research also assessed the negatives of the ground surveillance radar. One of the disadvantage of radar is the capability to detect only moving objects (vehicles, persons, aircrafts). Another negative is that the radars with their active radiation reveal their location. It is also necessary to be able to detect hidden threats (ambushes) and to mitigate the risk of destroying own forces. For this reason it is necessary that the optoelectronic set has a thermal detector that would allow to detect such a hidden threats.

It is necessary that the optoelectronic set is connected to the navigation system and at the same time supplemented by a laser rangefinder. Optoelectronic system serves not only for detection of threats, but also for the purpose of reconnaissance and determination of coordinates of points.

4.2 Unmanned Survey Vehicle Point Setting Requirements

According to the findings mentioned in chapter 3.2, one of the main tasks of the artillery survey units even at the maximum functionality of the navigation system is the creation of control navigation points, which will allow to refine the accuracy of the inertial navigation units.

This task is one of the most challenging in terms of the possible involvement of unmanned vehicles. The reason is that this point has to be precisely located and at the same time physically marked on the surface so the artillery (or other) units can easily find it and can run vehicles over these points to make a coordinates comparison.

Thus, the research team concluded that the solution to this problem must be viewed from two different points of view. The first is the location of a point in the form of an exact determination of its coordinates. The second is then the physical creation of a point on the surface of the terrain.

In terms of locating the points, this is a problem which is easily solved by the instruments which the vehicle must be equipped with to carry out the survey of maneuver axes and areas. If the survey UGV had an optoelectronic set supplemented by a laser rangefinder and linked to the INS/GPS navigation system, it would be possible to determine precisely the coordinates of the points targeted by this optoelectronic set. A problematic aspect is the accuracy of the measurement by the optoelectronic set and the possibility of distortion due to the terrain and interference with the accuracy of the measurement by the laser rangefinder (Varecha and Mušinka, 2019, Varecha, 2020).

An alternative solution may be the indented localisation of points based on the current position of the UGV. This option seems preferable in some cases, but requires the duplicate determination of UGV coordinates as output from the navigation system of the INS/GPS UGV survey unit.

It is also necessary to take into account the assumption of a software map tool, which will allow both the conversion of polar coordinates (direction, distance and position angle) into rectangular coordinates and plot them into a digitized map layer. However, this tool has already been created at the University of Defence and based on the evaluation carried out by the research team, therefore, the unmanned localization of coordinates is not a problem (Nohel and Stodola and Flasar, 2021).

The actual challenge for survey UGV is the creation of navigation control points. Control point

should be a ground metal target with cross marking the exact coordinates on the surface (Figure 1).

Figure 1: Civilian version of survey point (Matori and Atunggal and Cahyono, 2008).

The problem is how to firmly attach it to the earth's surface by the UGV.

In general, the determination of point coordinates on a theoretical basis is possible. Similarly, but with significantly greater problems, the actual creation of points in the field is theoretically solvable. In practical terms, however, a very specific technologies must be created first. For example a combination of existing technologies that would be able to physically realize this in the challenging conditions of military conflict.

5 CONCLUSIONS

Artillery survey is a compex solution to enable artillery operations. In current state of technological development it very often seem as a useless tool, but this is considered as a wrong point of view.

Artillery survey is still a key activity that must sustain even when autonomous weapon systems are being used, so that it can be used to support their function even when modern technologies fail or are just not available. As we can see from the current conflict in Ukraine, it is more than important not to rely solely on modern technologies, but to have a backup solution ready, which can represent the difference between the ability and inability to conduct fire.

The research and development of a new survey vehicle is guided by the reasons given, in which the use of unmanned platforms is also considered. The specified requirements for the survey UGV will be further compared with modern technologies and implementation possibilities.

The overall output of the project will be the design of crew and unmanned reconnaissance vehicle, which must be able to fulfil the tasks of artillery survey for both autonomous and non-autonomous weapon systems.

Current state of knowledge in terms of possible use of UGV in artillery survey is, that these vehicles can be used. Hovewer, there are some issues, that need to be solved – one of the biggest is development of technology which will allow placement of control points on precisely located spot by the UGV.

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