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SPATIAL POSITIONING WITH COMBINED METHODS OF TOPOGRAPHIC POINTS NECESSARY FOR ACCESSIBILITY OF FORESTS IN MOUNTAIN AREA

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Abstract

Since in the mountain area the area occupied by forest is over 60% of the area of the national forest fund, making forests accessible is an obvious necessity for the sustainable management of various forest resources. The research was carried out within the III Galbena production unit, Sudrigiu Forest District, within the scope of the Bihor Forestry Directorate, with the objectives of applying combined methods of spatial positioning of topographical details, necessary for the design and construction of transport facilities, in the perspective of making 15 inaccessible stands accessible, on an area of 174.48 ha. For the positioning of the topographical details, GNSS technology, GPS system and total station were used, and the working methods used are represented by real-time kinematic positioning (RTK), combined with polygonometric mapping framed with erasures, carried out with the total station. The use of modern combined methods for positioning topographic details in the inaccessible forest fund in the mountain area ensures the obtaining of products in alphanumeric and digital format with superior precision, necessary for the design and construction of transport installations in optimal technical conditions.

Key words: *combined technologies, contour lines, digital terrain model, forest accessibility, GNSS technology, spatial positioning.*

INTRODUCTION

The implementation of forestry strategies established by forest management plans relies on the existence of appropriate infrastructure to ensure effective access to the forest fund. In Romania, current infrastructure allows access to approximately 4.1 million hectares of forest - around 65% of the total 6.3 million hectares - within a maximum collection distance of 2.0 km. The remaining 2.2 million hectares (35%) remain inaccessible (Ciubotaru, 2007).

Internal accessibility works enable the creation of access networks within forest stands to support silvicultural operations, starting from the thicket stage, and the application of specific treatments (Order no. 2,534 of September 28, 2022). Improving accessibility aims to:

- enable operations across the entire stand under safe and efficient working conditions;
- prevent damage to retained trees;
- facilitate timber collection and reduce skidding distances;
- lower operational costs and increase recoverable wood volume.

Developing and maintaining a functional forest road network serves not only silvicultural, technical, and economic purposes but also:

- supports the rational exploitation and utilization of timber and forest products (Săndoiu, 2010; FAO, 2016);
- assists in forest fire prevention and control (Iordache et al., 2016);
- protects hunting species and biodiversity (Iordache et al., 2016);
- connects forest stands to primary transport networks;
- promotes sustainable forest management (Florescu & Nicolescu, 2000);
- enables recreation and tourism (Dumitru, 2014);
- contributes to local economic development.

Prior to establishing access infrastructure, a comprehensive field survey must be conducted to collect data on existing access routes (such as roads, paths, and parcel lines), their condition and dimensions, local hydrography, slope and terrain morphology, the structural and compositional characteristics of the stands (including density, age, and previous interventions), as well as the optimal directions for timber extraction.

This information helps determine the feasibility and urgency of access works, define road network layouts, estimate costs, and produce a sketch of existing and proposed routes.

Technical, ecological, and economic criteria for designing tractor roads include:

- Avoiding areas with natural regeneration;
- Operating during dry or cold weather to prevent road damage;
- Protecting edge trees using guards;
- Minimizing costs and route lengths;
- Avoiding marshy areas;
- Ensuring a transverse slope of 4–6% and terrain-specific longitudinal slopes;
- Designing a 3-4 m wide platform (OM 1540/2011);
- Incorporating safety features like curbs in dangerous bends;
- Installing temporary wooden bridges over streams;
- Ensuring proper gradient: 25% empty/10% loaded for universal tractors, 40% empty/18% loaded for forestry tractors;
- Mechanized, low-cost construction with daily maintenance using local materials;
- Fixing road alignments by a certified technician or engineer.

According to the updated OM 1540/2011, the maximum width of the tractor road is 4 meters. A standard example of its transverse profile is illustrated in Figure 1 (Ciubotaru, 1996).

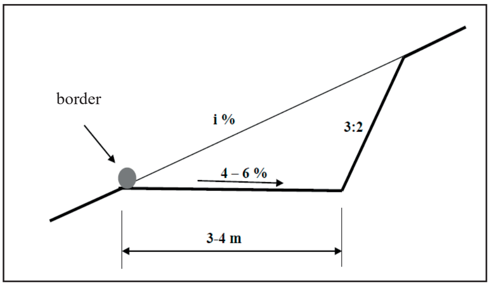


Figure 1. Transverse profile of the tractor road (Ciubotaru, 1996)

This study aims to analyze the spatial positioning methods used for detailed topographic points necessary for designing transport infrastructure in mountainous forest stands with extremely low accessibility. These detail points will be positioned using suitable technologies and surveying methods tailored to the site conditions.

MATERIALS AND METHODS

The research was conducted in inaccessible deciduous and coniferous stands located in a mountainous area, within Production Unit (P.U.) III Galbena, managed by the Sudrigiu Forestry District under the authority of the Bihor Forestry Directorate. The study was carried out in the context of doctoral research.

The targeted stands are located in plots 43B, 44A, 44D, 44C, 45A, 45B, 46A, 46B, 47A, 47B, 47C, 47D, 48A, 48B, 48C, and 49A, covering a total area of 174.48 ha in a highly inaccessible mountainous region (Figures 2 and 3).

The research methodology included bibliographic review, direct observation of trees and access routes, experimentation, simulation, comparative analysis, and image recording on digital media.

The bibliographic documentation phase provided a thorough understanding of the need to improve accessibility in the studied forest areas and its implications for forestry operations. For this purpose, the forest management plan, the associated management map, and the applicable technical regulations were examined.

In addition, documentation regarding available technologies and equipment for high-precision spatial positioning in mountainous deciduous and coniferous stands was also required.

Figure 2. Case study location (https://www.google.com/maps/d/viewer?mid)

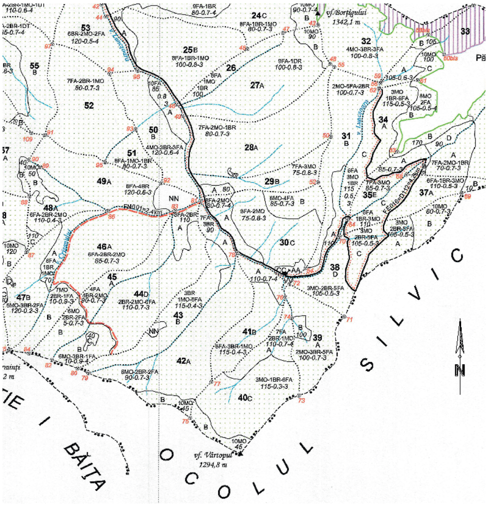


Figure 3. Positioning of the researched and studied stands (according to the Management Map of U.P. III Galbena, 2014)

The positioning of topographic detail points was carried out in the inaccessible stands, including those located in plot 43B, characterized by steep slopes, dense forest vegetation, and limited access infrastructure. Figure 4 illustrates the specific field conditions encountered during the positioning work in this plot.


Figure 4. The inaccessible grove in plot 43B where the positioning of the topographic detail points was carried out (original photograph)

Field observations were conducted by thoroughly surveying the designated stands, during which the proposed routes for forest road construction were identified. Characteristic topographic detail points were also marked and spatially positioned to determine their planimetric coordinates and elevations within the national reference system.

The experiment involved positioning these detail points, determining their coordinates, graphically representing them, and proposing accessibility solutions for the study area. GNSS technology, specifically the NAVSTAR GPS system, as well as total station measurements, were employed for this purpose.

Previous and recent studies have shown that satellite-based positioning in forested areas is significantly influenced by the structural and functional characteristics of the stands. These factors can lead to statistically significant variations in spatial coordinates. Variables such as DOP values affect the precision - though not the accuracy - of the topographic point coordinates (Căteanu & Moroianu, 2024).

One viable method for positioning forest detail points under specific working conditions using GNSS technology is the static method - applied in traditional, rapid, or GPS tracking variants (Ádám et al., 2004). This approach involves placing a GNSS receiver at the point of interest for a variable period, while three additional receivers are stationed at control points with known coordinates. The duration of each stationing depends on technical and environmental conditions, as well as the spatial configuration of the known reference points, either from legacy geodetic networks or the passive GNSS network.

Final coordinates are obtained through post-processing of the satellite data, with results varying depending on the software and computational algorithms used. Despite offering high precision and accuracy, this method is time-intensive and requires well-trained personnel, which limits its current widespread use (Crainic, 2011).

Recent comparative studies using four GNSS receivers - both GIS - and geodetic-grade - revealed notable differences in performance. The GIS-grade receiver yielded an accuracy of 1.38 m and a precision of 1.29 m, whereas the geodetic-grade receiver achieved 0.74 m in accuracy and 0.91 m in precision. These discrepancies, despite identical data collection conditions, are primarily attributed to the distinct operational principles and processing algorithms of each device type, alongside forest-specific challenges such as cycle slips and the multipath effect (Brach, 2022).

The real-time kinematic (RTK) method is widely used today for positioning various topographic features, due to its high precision, operational efficiency, and accessibility when appropriate logistics and infrastructure are available. In forestry, spatial accuracy is critical for numerous applications, and GNSS-based technologies provide effective solutions for acquiring geolocation data (Căteanu & Moroianu, 2024).

RTK delivers results almost instantaneously - within fractions of a second - after data acquisition and transformation into the national reference system. The method can be applied in two configurations: short-range and long-range (Ádám et al., 2004). The applicability of the long-range variant was significantly expanded following the introduction of the ROMPOS service in August 2008, which enabled high-accuracy transformation parameters across regional and geographical zones. In this configuration, the base station is a permanent GNSS reference point, allowing real-time positioning of detail points using a rover at distances of 30-70 km (Figure 5).

Drones equipped with high-precision GNSS receivers offer another alternative for field measurements, significantly reducing time on site while ensuring high data accuracy. However, recent studies indicate that the RTK method yields superior accuracy, particularly in elevation data for forest road longitudinal profiles. For instance, using drone-based GNSS data resulted in over 22.64% higher calculated embankment volumes compared to RTK-based point positioning, highlighting substantial discrepancies (Lepoglavec, 2023).

The short-range application of the real-time kinematic (RTK) method involves the use of two dual-frequency GNSS receivers: one is stationed at a spatially determined base point, while the other (rover) is used to record data at target points, with short occupation times. To ensure real-time positioning, both receivers must be equipped with radio modules for transmitting and receiving satellite data and differential corrections (Crainic, 2011; Pica, 2022).

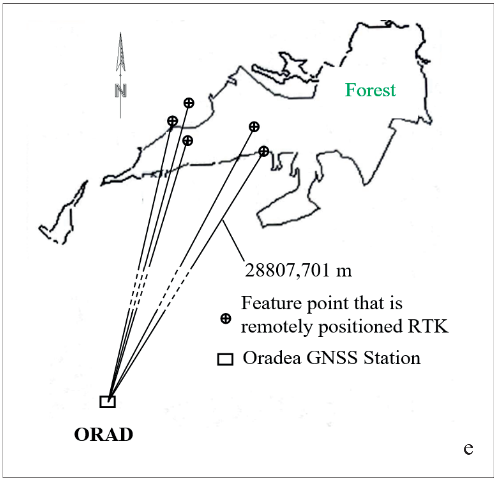


Figure 5. The method of positioning topographic points in the forest fund using the RTK method at long distance (adapted from Crainic, 2011)

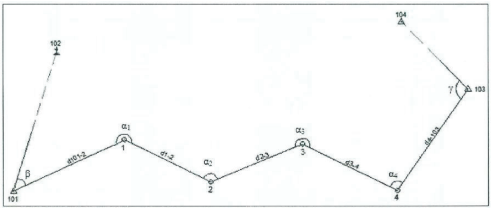
This approach is effective even in forested environments, particularly when the base receiver uses a 4W internal radio and the rover a minimum 2W radio. Under these conditions, the connection between the devices is reliably maintained up to 10-12 km, and data transmission can reach distances of 22-25 km, regardless of terrain complexity.

Recent studies demonstrate that individual tree selection for extraction can now be conducted using digitally acquired data from forest inventories. Consequently, tree locations can be identified in real time using RTK-GNSS with dual-frequency receivers and short-range radio communication. When operating within 1 km of the base station, the horizontal positioning error (RMSE) was found to be 0.26 m in *Larix kaempferi* stands and 0.48 m in *Pinus koraiensis* stands, confirming the method's reliability for detailed forest applications (Cho et al., 2024).

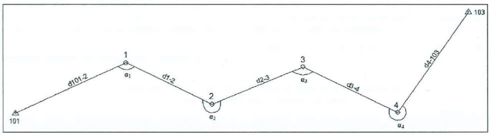
With the introduction of additional satellite systems such as BEIDOU, GALILEO, and QZSS - alongside GPS and GLONASS - the broader concept of Multi-GNSS has emerged. This integration increases satellite availability, enhancing performance under challenging conditions like dense canopy cover. Studies in forest environments with 40–90% tree cover confirm that RTK positioning using Multi-GNSS systems provides superior coordinate accuracy compared to traditional GNSS RTK, even in areas with highly restricted satellite visibility (Andreas, 2019).

For accuracy assessment of GNSS-based coordinates in forested areas, reference values are typically obtained using high-precision total stations via polygonometric traverses, supported by orientation marks. These measurements are processed with specialized software using rigorous adjustment models (Feng et al., 2021).

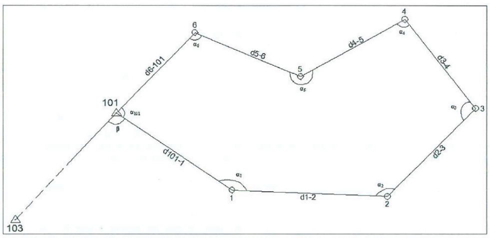
When satellite positioning is impractical due to forest canopy or rugged terrain, several polygonometric surveying methods may be employed to determine new point coordinates: (i) framed (supported) traverses on spatially defined points with orientation marks (Figure 6.a), (ii) unsupported traverses without orientation marks (Figure 6.b), and (iii) closed traverses with orientation marks (Figure 6.c). These methods are carried out using advanced total stations, with robotic models offering the highest efficiency (Sabău, 2010).



a. Main traverse supported (framed) with orientation visas



b. Main traverse supported without orientation visas



c. Main traverse closed with orientation visas

Figure 6. Principle of creating polygonometric roads (Cranic, 2011)

This method is frequently used in the preparation of forest maps, when carrying out the forest management plan.

Considering the particular conditions of spatial positioning of topographic points on surfaces covered with forest vegetation, efficient combinations of modern geospatial technologies can also be used. Consequently, their positioning principles will be integrated, ensuring obtaining coordinates characterized by superior accuracy and precision.

The positioning of various topographic details in the forestry sector and the preparation of related graphic representations can currently be achieved using combined working technologies such as GNSS systems and total stations. Consequently, alphanumeric and graphic final products of high accuracy and precision are obtained, directly correlated with the logistics used and the working methods used (Călina et al., 2020).

In extreme working conditions, determined by the lack of points in the classical geodetic network or the passive GNSS, the free station method can also be applied at the limit. In this case, a total station and at least two accessible points of known coordinates are required, which have usually been positioned with satellite recordings. As a result, an intersection will be made at the limit, and the point where the total station will be stationed can be determined with high precision through post-processing, if specialized calculation programs are used, with rigorous compensation, for example TERRAMODEL, MATLAB (Crainic, 2011; Nero, 2023). In this situation, a major inconvenience arises regarding logistics and, respectively, working time.

The logistics used to carry out the case study are relatively varied.

Currently, the use of low-cost multi-constellation and multi-frequency receivers for obtaining high-precision coordinates in various stands of deciduous and coniferous trees is facilitated by the use of high-performance software for data recording and processing. For example, the Google Pixel 5 smartphone model and the u-Blox ZED F9P standalone receiver are two variants of low-cost receivers that can be used to position details under the tree canopy. Obtaining accurate results with these receivers was facilitated by using the latest version of the

Demo5 fork of the RTKLIB software. Consequently, the use of low-cost receivers can be effective in the variant of using high-performance software, but also with hardware improvements, especially of the antenna, which is an absolute priority (Tomaštík & Everett, 2023).

Although there is currently a wide range of GNSS receivers and various satellite constellations, the spatial positioning accuracy in trees depends on the class of the receiver, and obviously on the working methods. As a result, geodetic-class GNSS receivers ensure superior accuracy, even in the case of autonomous solutions, compared to modern dual-frequency Smartphones. The obvious differences in accuracy between the various types of satellite receivers are mainly determined by their composition and the software used to record and process satellite information. Consequently, geodetic-class receivers ensure the determination of highly accurate coordinates, in the centimetric-decimetric range, and modern Smartphone-type receivers determine coordinates with GIS accuracy, in the metric-decametric range (Purfürst, 2022).

The logistics used for spatial positioning were provided by S.C. TOPOCONSULT S.R.L. from Oradea, Bihor County, Romania, and were represented by:

- two dual-frequency GNSS receivers, one TRIMBLE R10 with internal 4W radio for the base, and the other TRIMBLE R12I with external 2W radio, as rover;
- TRIMBLE S8 robot total station with all related accessories;
- recordings from the Beiuş GNSS station, using the ROMPOS service;
- TRIMBLE ACCESS program for collecting and processing field data.

The MapSys10.0 program for graphical reporting of positioned points, creating the database and obtaining the related graphic products in digital format was used within the topography laboratory.

The forest management plan (management plan) for Production Unit (P.U.) III Galbena and the forest map at a scale of 1:20000 in digital format, for the area of Production Unit (P.U.) III Galbena, were provided by the Sudrigiu Forest District, Bihor Forestry Directorate.

The experiment related to the case study (research) was carried out in several integrated stages, depending on the working methods used and the working conditions in the field.

In the first stage, the point that was used as a GPS base was established. It was located at an appropriate altitude, in order to receive and record satellite data in optimal conditions.

In the second stage, in order to carry out measurements with the total station, the routes on which the supported polygonometric roads were carried out were established. These were designed through the plots that are to be covered with silvotechnical interventions, and implicitly to be accessible. Consequently, the station points were established and materialized on the ground, where the device will be stationed.

In the next stage, the points that were positioned with GNSS technology, as points for thickening the support network, and which were used to support the polygonometric roads, were established and materialized.

These were located in areas where there were optimal conditions for receiving the satellite signal, without obstructions. These were mostly represented by the open meshes for the installation of natural regeneration, in the stands engaged in the exploitation-regeneration process, and in those caused by felling and wind breakage, as a result of extreme weather phenomena. It was also necessary that they could be observed and targeted from the nearest polygonometric survey station points, in order to comply with the rigorous data processing and compensation algorithm.

All the projected points that were positioned were materialized on the ground by wooden posts with a square section, 5x5 cm, and the mathematical center of their cross-section was marked with a nail, at the intersection of the diagonals.

In the next stage, the base point was positioned with the remote RTK method and the ROMPOS service, the records from the Beiuş GNSS station being also used. Also, the density points were positioned with the RTK method, at a shorter distance, thus using radio modules, in areas where working conditions did not allow the recording of satellite data in optimal conditions.

The last field stage was represented by the completion of the polygonometric journey, which involved stopping at each station point, performing direct and reciprocal sightings, and sighting the points determined from the stations with visibility.

Currently, hierarchical models are being designed for collecting and sharing forest and natural resource management data, which are based on the accuracy and variety of different spatial positioning and location hierarchy methods in the forestry sector. As a result, data with diverse spatial and temporal complexity are transmitted and processed incrementally at lower levels of organization, then merged, synthesized and transmitted to higher levels of management for sustainable forest and natural resource management (Keefe et al., 2019).

The data processing stage and obtaining the final coordinates in the national reference system was carried out differently, depending on the positioning technologies and methods used.

The sequence of the work stages described above is presented synthetically in Figure 7.

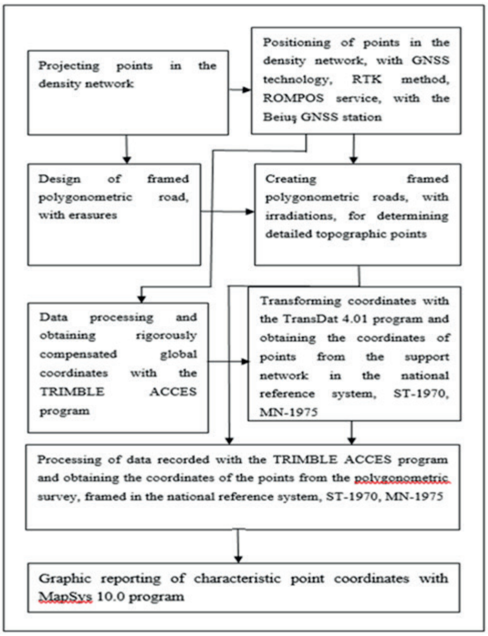


Figure 7. Work steps

After reporting the coordinates of the characteristic points, the obtained travel routes and the optimal accessibility options were simulated, compared and analyzed.

RESULTS AND DISCUSSIONS

The satellite recordings were processed in real time, with the TRIMBLE ACCESS program, obtaining the ellipsoidal coordinates. These were transformed with the TransDatRO4.01 program, using the national transformation parameters recommended for the work area, thus resulting in the final coordinates, in the national reference system (Table 1).

From the analysis of the results of studies conducted in accessible stands of deciduous and coniferous trees, the accuracy of single-frequency GNSS receivers does not depend so much on forest conditions, while the performance of the tested dual-frequency geodetic receiver is very sensitive to satellite visibility. Consequently, in the variant of calculating coordinates with post-processing, especially in combination with data obtained with an IMU inertial system, the improvement of the accuracy of the dual-frequency receiver was significant. As a result, the accuracy of the planimetric coordinates determined with the dual-frequency receiver in real time was 0.7 m, and for the single-frequency receiver, the accuracy ranged between 4.2-9.3 m. The final conclusions resulted from comparing the results obtained with single and dual frequency GNSS receivers, in motion, with those obtained with the total station and a dual frequency GNSS receiver, using the RTK method, for the positions of 224 trees, on the studied route (Kaartinen, 2015).

The data that were recorded during the supported polygonometric surveys were also processed with the TRIMBLE ACCESS program, obtaining directly the final coordinates, in the national reference system (Table 2).

In the case of this case study, the precision of determining the coordinates in the horizontal plane is 3-4 cm and in elevation, 5 cm, an aspect that is also conditioned by the performance of the transformation parameters in the national reference system, for the analyzed location.

All the final coordinates were transferred to a file with the extension txt., configured in five columns, respectively: point number, X (m), Y (m), Z (m) and the code - which represents the layer into which each point will be imported. The points were graphically reported with the

MapSys program 10.0 (Marton, 2007), thus materializing their planimetric position, in the layer corresponding to the code established since the positioning. By joining the station bridges, the routes of the polygonometric roads materialized (Figure 8).

Additionally, sightings to the reference points with known coordinates materialized and used for the precise adjustment of the polygonometric trails. An analysis of the images presented in Figure 8 reveals that the sides of these trails exhibit considerable variability in length. Additionally, sightings to the reference points with known coordinates materialized and used for the precise adjustment of the polygonometric trails.

Table 1. Inventory of coordinates in the national reference system, related to topographic points that were positioned using the RTK remote method

Point No.	X (m)	Y (m)	Z (m)	Code	Point No.	X (m)	Y (m)	Z (m)	Code
1	561004.742	322025.555	1200.828	6	110	562489.607	321574.075	1074.115	6
100	560879.530	321851.244	1236.724	6	111	562399.153	321725.809	1060.914	6
101	560953.860	560953.860	1243.117	6	112	562318.575	322022.644	1024.108	6
102	561437.915	322641.031	1239.886	6	113	562285.771	322118.263	1004.991	6
103	561479.926	322729.207	1009.112	6	114	562422.511	321401.689	1046.621	6
104	561578.910	321397.537	1168.185	6	115	562380.634	321451.243	1044.822	6
105	561706.634	321354.264	1162.224	6	116	562253.608	321637.594	1013.201	6
106	562127.977	321324.216	1087.116	6	117	562320.780	322664.116	873.125	6
107	562651.561	321397.707	1105.991	6	118	562261.863	322675.991	864.212	6
108	562569.315	321444.056	1086.285	6	119	562186.328	322727.992	845.250	6
109	562571.015	321555.389	1104.115	6	-	-	-	-	-

Table 2. Inventory of coordinates in the national reference system, related to topographic points that were positioned by the method of polygonometric mapping

Point No.	X (m)	Y (m)	Z (m)	Code	Point No.	X (m)	Y (m)	Z (m)	Code
11	560965,458	321908,829	1213,268	7	54	562221,139	321264,182	1071,314	7
12	561003,845	321914,341	1208,556	7	55	562162,511	321253,015	1084,322	7
14	561170,524	321985,211	1142,460	7	56	562069,775	321249,589	1114,382	7
15	561281,444	322007,952	1140,224	7	57	562033,482	321320,500	1117,328	7
16	561415,182	322022,118	1107,524	7	58	561986,884	321369,045	1121,369	7
17	561560,658	322045,867	1075,334	7	59	562032,924	321441,664	1188,754	7
18	561643,557	322025,844	1065,614	7	60	562087,084	321516,484	1057,232	7
19	561727,310	322027,240	1060,228	7	61	562122,111	321549,639	1043,875	7
20	561814,962	322039,725	1047,284	7	62	562147,412	321595,005	1030,422	7
21	561975,561	322163,689	986,436	7	63	562172,713	321646,479	1016,638	7
22	562117,076	322342,265	938,624	7	64	562188,067	321770,190	996,658	7
23	562179,084	322471,309	918,317	7	65	562190,161	321835,797	988,458	7
24	562210,471	322569,782	898,116	7	66	562190,738	321892,296	984,841	7
25	562252,596	322642,811	876,232	7	67	562225,128	321939,612	986,448	7
26	561061,177	322002,359	1175,300	7	68	562224,037	322025,765	974,339	7
27	561138,351	322058,343	1142,446	7	69	562204,407	322111,918	965,766	7
28	561211,416	322110,558	1138,140	7	70	562170,601	322204,614	954,724	7
29	561306,511	322171,628	1112,334	7	71	563153,152	322286,405	985,065	7
30	561407,713	322226,592	1077,424	7	72	562162,182	322357,141	937,382	7
31	561502,532	322290,445	1048,742	7	73	562751,684	321394,057	1126,482	7
32	561526,388	322167,759	1047,845	7	74	562708,062	321344,982	1115,937	7
33	561635,473	322383,303	1023,642	7	75	562624,908	321331,351	1085,164	7
34	561717,264	322454,188	1007,649	7	76	562550,752	321352,071	1065,142	7
35	561812,473	322462,452	978,684	7	77	562509,699	321401,640	1063,113	7
36	561893,246	322475,357	968,846	7	78	562472,708	321435,839	1057,224	7
37	561969,043	322488,897	952,167	7	79	562432,925	321490,279	1045,228	7
38	562069,773	322502,921	933,748	7	80	562394,683	321537,044	1040,932	7
39	562137,932	322554,041	921,116	7	81	562359,305	321605,745	1031,854	7
40	561522,798	322758,517	1010,115	7	82	562317,138	321656,846	1022,428	7
41	561592,661	322729,550	1025,889	7	83	562274,971	321692,580	1014,932	7
42	561693,195	322724,438	1038,869	7	84	562251,029	321761,549	1004,992	7
43	561774,986	322669,911	1003,892	7	85	562224,585	321819,082	994,912	7
44	561836,329	322593,232	992,348	7	86	562687,887	321472,031	1024,938	7
45	561878,394	322546,826	978,214	7	87	562640,176	321511,563	1117,624	7
46	561552,545	321438,734	1169,224	7	88	562591,456	321645,804	1125,005	7
47	561612,341	321455,807	1143,229	7	89	562556,734	321743,342	1129,995	7
48	561634,305	321510,022	1130,985	7	90	562460,412	321880,450	1106,311	7
49	561661,976	321562,812	1121,314	7	91	562403,977	321986,506	1076,261	7
50	561676,385	321633,867	1118,117	7	92	562335,272	322101,012	1036,227	7
51	561696,095	321712,651	1110,119	7	93	562279,655	322172,988	1002,639	7
52	561735,515	321807,907	1097,318	7	94	562215,313	322241,692	968,227	7
53	561762,595	321921,602	1088,618	7					

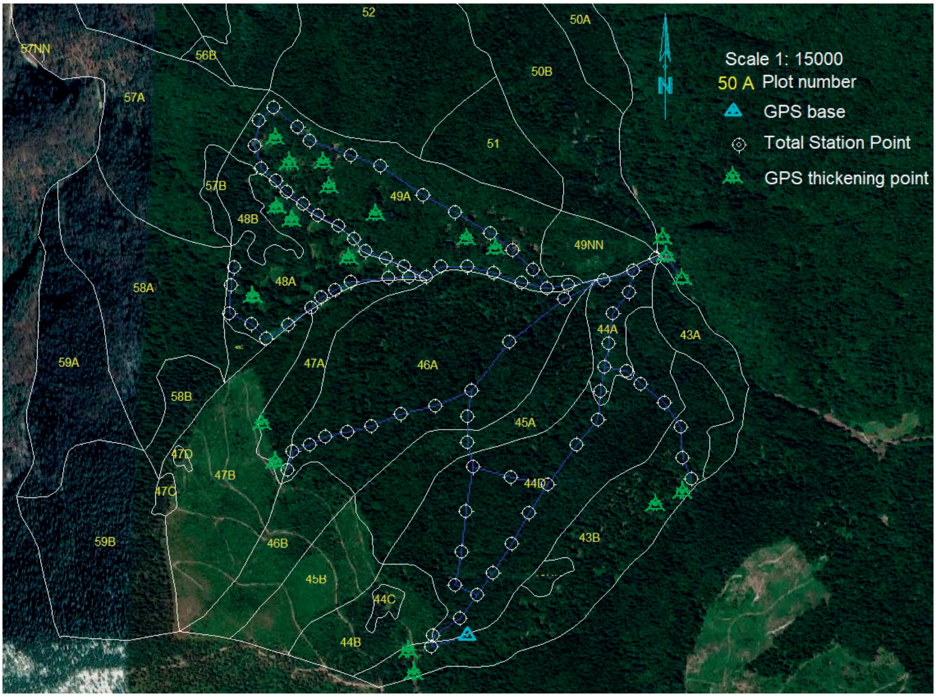


Figure 8. Establishing the GPS base point and total station points
(image capture from MapSys10 program)

An analysis of the images presented in Figure 8 reveals that the sides of these trails exhibit considerable variability in length. This variation is primarily due to limited visibility between station points, caused by the presence of standing trees and natural seedling biogroups within the forest stands. As a result, side lengths range from 34.450 meters to 227.850 meters.

Similarly, the lengths of the sightings to known coordinate points vary depending on their spatial distribution and the presence of visual obstructions such as forest vegetation. The established trails crossed plots undergoing natural regeneration processes, where timber harvesting is currently in progress. In plot 49A, a closed road was constructed and marked with orientation signs to support the efficient planning of transport infrastructure, given the favorable positioning of the area. This newly created road also supports the route along the southern and southwestern boundary of plot 48A.

Closed roads equipped with orientation signs were also constructed in plots 44A, 44D, 45A, and 46A. In contrast, plots 43B and 46 were traversed by supported roads, given their specific positioning and topographical context. The design and implementation of transport infrastructure to improve accessibility in the studied areas will be carried out in stages, in accordance with the current forest management plan and the strategic guidelines established at the forestry district level.

Considering both the provisions of the forest management plan and the dynamics of natural regeneration, priority will be given to the design and construction of transport facilities in plots 43B and 49A (Irimie & Timofte, 2023). Subsequent interventions will focus on improving accessibility in the other plots undergoing natural regeneration - namely 44A, 44D, 45A, 46A, and 48A - based on the condition of the forest stands and the urgency of regeneration and timber harvesting operations.

As a result, roads have also been constructed in stands where maintenance works for natural and mixed regeneration are planned, as well as in those targeted for tending and management cuttings in young and mature stands, depending on their developmental stage.

Regardless of the segment, the spatial coordinates of key topographical detail points will be determined using the total station method, integrated along the full length of each route. The proposed transport infrastructure solutions must ensure full accessibility for all forest stands subject to silvicultural interventions, in compliance with the current forest management plan and applicable technical standards.

Finally, the prioritization of routes and accessibility options for the studied stands will be established through simulations evaluating the realistic potential for timber valorization over the designated management period.

CONCLUSIONS

Making the forest fund accessible is an essential condition for sustainable management of forests and respectively for the optimal valorization of their wood and non-wood products.

In order to design and build an infrastructure corresponding to the transport facilities in inaccessible mountain areas occupied by deciduous trees mixed with softwoods, and mixtures of softwoods, it is necessary to spatially position the characteristic detail points with high precision.

The use of G.N.S.S. technology, of the G.P.S. system, with TRIMBLE R10 and TRIMBLE R12I dual-frequency receivers, for the positioning of GNSS bases (topographic points of the support network density) in the forest fund, by the remote RTK method, using the records from the Beiuş GNSS station, represents an optimal technical solution.

The positioning of the points necessary for carrying out the supported polygonometric surveys, with the total station, from the GNSS bases, was carried out in optimal conditions using a GNSS receiver with two frequencies with an external 4W radio module for the base, and one with an internal 2W radio module for the rover.

The use of the TRIMBLE S6 robot total station for carrying out the supported polygonometric surveys with radii facilitated the spatial positioning in optimal conditions of the characteristic detail points related to the accessibility variants studied and analyzed.

The variants of transport installations studied and analyzed must ensure the accessibility of all the stands that will be traversed with various silvotechnical interventions, in accordance with the forestry management in force, and respecting the technical norms in force.

The ranking of the routes and accessibility variants of the studied stands will be carried out after simulating the real possibilities of valorization of the wood that will be exploited from them, for the established period of time.

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