Study on the efficiency of using motorized levelling in vertical geodetic networks

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Abstract
This paper proposes a general analysis of levelling works automation, which focuses on the precision and efficiency achieved by using motorized levelling, compared to the classic one. It presents the current state of research in the application of motorized levelling in some countries in Europe and the US, both in terms of equipment and methods of computation, in geometric and trigonometric levelling. The case study done on the road of the DJ 248B Horleşti, Rediu commune, Iaşi County, on a section of one kilometre, uses the motorized geometric levelling method and the traditional one to draw the necessary conclusions about measurement process optimization, as well as the extension of works in the national vertical geodetic network.

Keywords
Geometric levelling, trigonometric levelling, motorized levelling, precision, efficiency.

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1. Introduction

The concept of "motorized levelling" is defined as a levelling procedure in which the vehicles are a part of the measuring system, as opposed to being used for transportation only, during on-site operations (Rockville M, 1980). The full procedure entails the use of three vehicles for the measuring instrument and the two rods, each of them being accompanied by an operator. The vehicle carrying the measuring instrument needs to be adjusted so that observations will be possible without the operator and the instrument leaving the car and also needs to be equipped with all the devices that are necessary for recording distances, sending data and performing the verification calculations. The vehicles carrying the rods need to have accessories that will ensure the vertical position of the rods during the observations. According to the nature of the vehicle (pickup truck or motorbike), the operator helps place the rod in the right working position, but the aim is to have a process that comprises as few operations as possible and is, therefore, as effective as can be.

The motorized levelling method provides the possibility to establish the line of sight at a greater height than in the case of classical levelling, which depended on the height of the observer, if the structural design is adequate for the observing vehicle. Among the technological advantages of raising the line of sight we can mention the decrease in vertical refraction occurring in the first two meters of the atmosphere, characterized by turbulence and higher temperatures, and the uniformization of the measured distances on the levelling itinerary. One of the major benefits of motorized levelling is that it diminishes the fatigue of the field staff, which leads to obtaining results which are equally good throughout the day, as the risk of measuring mistakes is low. (Chrzanowski A., 1989)

The use of motorized levelling can be adjusted according to the nature of the measured itinerary – it can be applied as middle geometric levelling or as unidirectional/leap-frog/reciprocal trigonometric levelling. Considering the distinctive equipment used in the case of the two types of levelling, greater attention needs to be paid to the measurements using a total station, which is more sensitive than the levelling instrument when it comes to vibrations and to the change of the vertical position during on-site observations. The calculations needed for establishing the height differences are more complex in the case of trigonometric levelling and they can have multiple solving variants, according to the work hypotheses and to the precision required by the measurement project (Ceylan A., 2005).

2. The evolution of the research regarding the levelling works automation

The first research regarding the use of motorized levelling appeared at the beginning of last century (1916), in the US, where they used especially modified cars in order to check the railroads and telegraph lines.

After World War II, motorized levelling was performed in a new way, for projects with a precision up to the third order, using a pickup truck. The procedure took place in a semi-automated way, meaning that both operators, from the instrument and the rod, left the car during the measurements.

A new stage in the development of motorized levelling consisted in using three vehicles. For a lower financial cost and other technical reasons, the US National Geodetic Survey chose the variant using a pickup truck and two motorbikes. Due to the specific conditions of the area, involving long trips to the work point, the pickup truck was made so that it would transport the whole measuring equipment (the level instrument, the rods and the two motorbikes), as well as the operators for the instrument and the rods. On each side of the car, a wing was installed in order to allow the observer to perform the observations on both sides of the car, according to the conditions of the road. A special device installed on each side of the vehicle was able to lift the tripod and the measuring instrument when the vehicle was in motion and to lower it when it stopped for observations towards the rod (Figure 1).

Fig. 1 The observer with the measuring instrument (NOAA Photo Library)

We can see in the figure that one leg of the tripod is fixed in that “wing” installed laterally on the car, while the other two legs of the tripod stay on the ground. The observer is sitting on a swivel chair and is protected by a retractable roof which is useful in case of bad weather.

The motorbikes transporting the rods needed some technical modifications and had to allow for the movement of the rods between points, in a horizontal position, and for their support in a vertical position on the levelling turtles. The modifications of the system of positioning of the rod allowed it to revolve completely around the vertical axis, for readings backward and forward in successive stations. The suspension system had the possibility to operate on the levelling turtle by means of a hand lever, so that the rod would become vertical without the operator leaving the vehicle (Figure 2).

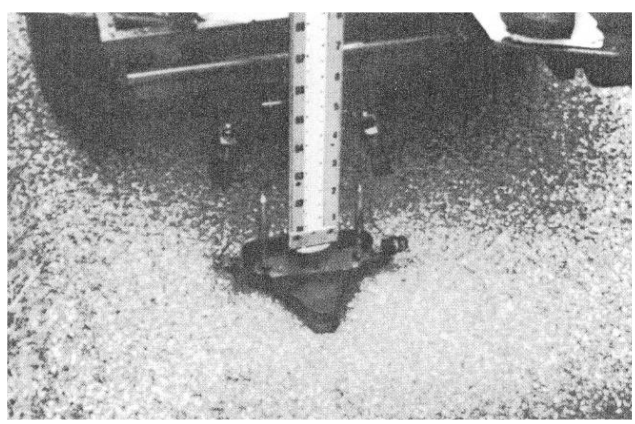

Fig. 2 Placing the levelling turtle on the ground (NOAA Photo Library)

Outstanding results were obtained in the '80's, for a series of levelling lines in the tested areas, with a precision up to ±1 mm/km of double levelling and a productivity that was 30% higher (Rockville M, 1980).
In Europe, a considerable contribution was made by the German researchers, who used the motorized levelling with three cars at the beginning, obtaining precisions of 0.2–0.4 mm/km, together with an increase in productivity and the improvement of the on-site working conditions. They also used an approach with two motorbikes instead of the cars used as rod vehicles, resulting in a similar precision of ± 0.5 mm/km, with a productivity rate which is double compared to the traditional method. This higher productivity resulted from an extended levelling, much greater than in the experimental study of the NGS (US), which took place on 100 km.
Motorized levelling was also used in other European states, especially in the Northern area, such as Denmark, the Netherlands, Poland, Norway and Sweden.
The Swedish variant is worthy of attention, as it was used after 1970 for re-establishing the national levelling network. It is a development of the German variant, using three cars as vehicles – one for the instrument and the other two for the rods (Figure 3). The operators only leave the cars for positioning the rod. One of the technical improvements is the construction of a special tripod with long, adjustable legs and special plates for the legs, in order to diminish the effects of instability and the influence of vibrations, wind and temperature variations. A field computer was used for the first time, allowing for the storage and performance of automatic on-site checks of all the data in the observations. They also built an automatic comparison rod with a laser interferometer. That makes it possible to calibrate and calculate corrections for each graduation on the invar rod.

Fig. 3 Performing measurements by motorized levelling with three cars (Oresund Bridge, 2000)

The experience concerning modern levelling techniques has expanded for over 50,000 km of levelling under various relief conditions, with various teams and work instruments. We should note that daily productivity has been assessed to 12 km of levelling, working 5.5 hours/day.
In 1985, two new modern methods of motorized measuring were developed: the motorized trigonometric levelling technique and the XYZ motorized technique (Becker J.M., 1986). The instruments are placed centrally in the specially modified cars. Both techniques use modern total stations instead of the classical levelling instrument used previously in the motorized geometric levelling. The performances of these techniques were surprising both in quality and in quantity.
For the motorized trigonometric levelling, the equipment was made of three identical pickup trucks. Each vehicle was equipped with an electronic total station with a vertical target and a reflector. The standard deviation for measuring angles was 1.5^{cc}, and for distances it was 3 mm + 2 ppm. The tripod was especially built with a height above 2 m in order to diminish the vertical refraction effect. It was installed centrally in the back of the car and the legs of the tripod could be lowered directly to the ground through three holes in the vehicle floor. For stability reasons, each leg of the tripod had a round steel plate with spikes at its base. In order to simplify the lifting and lowering of the tripod during transportation, an electrical winch was installed.
The measuring methods are differentiated according to whether the observations are performed on benchmarks or between the vehicles. In the first case, a rod was used and 4 targets were placed on it at the distances of 1.5 – 2 – 2.5 – 3 m. The distance from the base of the rod to the target was measured with a laser interferometer with a deviation up to 0.1 mm. The height difference between the benchmark and the instrument is calculated according to the standard formulas. In the second case, when the height difference is between vehicles, it is performed by calculating the slant distance measured in both directions (with a maximum deviation of 5 mm on lengths up to 350 m), and respectively by measuring the vertical angles reciprocally and simultaneously, by the average of three determinations. The physical corrections were applied directly on-site, after the transfer of the data to the computer in real time, thus permitting the direct checking of the observations in the station. The results obtained on the test lines, after approximately 10% of the measurements were redone, led to a standard deviation of about ± 0.5 mm/km – results that are similar to the motorized geometric levelling technique (Becker J.M., 1988).

3. Case study: Using the motorized geometric levelling on a section of 1 km on the road section DJ 248B

This case study endeavours to show the efficiency of the motorized geometric levelling for determining height differences corresponding to the I-II levelling network order, compared to the traditional one.
The observations were performed in Rediu commune, in Horlești, on the county road DJ 248B. The use of the classical and motorized geometric levelling was performed

on a road section of 1 km, both ways, the average height difference between the end points being approximately 5 m (Figure 4).

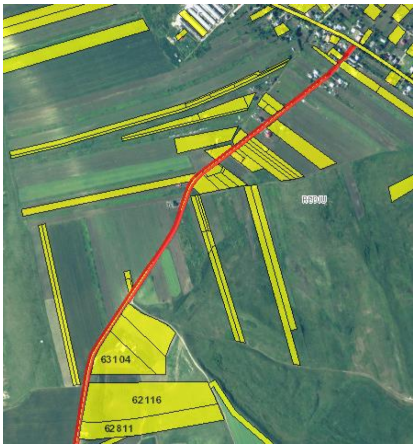

Fig. 4 The traverse of geometric levelling in the study area

The measuring equipment consisted of a Leica Sprinter 100M digital level and two bar code level rods. The level is equipped with the necessary element for processing the digital electronic image for determining heights and distances and the bar code on the rod is read completely automatically by electronic means. The standard deviation for 1 km of double levelling, according to the technical specifications, is ±2.0 mm. The Leica Sprinter bar code rod, made of aluminium, is 5 m long.
The motorized geometric levelling was performed with three pickup trucks: Mazda BT-6, on which the measuring instrument was installed, and Dacia 1305 and Dacia Logan for the transportation of the bar code rods.
The tripod of the level is placed centrally, in the back of the car, when it is in a measuring position (Figure 5).

Fig. 5 The vehicle equipped with the measuring instrument

When the level is installed, the tripod is placed in a special star-shaped device. The gripping system of the device is based on a metal frame with the length of 1.2 m, the width of 1 m and the height of 10 cm (Figure 6).

Fig. 6 The position of the tripod on the metal frame

The gripping system of the bar code rods on the two transportation vehicles was created by building a metal frame on which a pair of vice-pincers was welded, having a slow release mechanism and allowing the bar code rod to be placed in a fixed position (Figure 7).
The method of placing the bar code rods on the ground is the classical one. For this study, no special gripping device between the rod and the levelling turtle was made. The operator has to get out of the car and to place the turtle on the ground manually. The type of turtle used for the motorized geometric levelling is a simple metal one, whose upper part is a hemisphere.

Fig. 7 The gripping system for placing the rod at the back of the vehicle

In the on-site operations, the levelling line was divided for a distance between successive points of approximately 100 m. The observation procedure was not modified, using the standard sequence of reading on the rod (backward and forward). After performing the operations towards the "backward" point, the operator on the instrument signals to the person with the rod who is at the "backward" point to move to the "forward" point for the next observation station. That person puts the rod in a transportation position and drives to the next point. At the same time, the observer goes to the next station point. The person with the rod at the "forward" point will remain on the same position, because that will become the "backward" point for the next station, the rod remaining fixed on the turtle, but rotated at 180 degrees.

Based on the on-site observation (double motorized and classical levelling), the height differences for each station were determined by subtracting the average values of the measured heights to the "backward" and "forward" points. The total value of the height difference for the whole levelling line was obtained by adding the partial height differences for each station.

The calculation performed for the motorized geometric levelling is shown in table 1. It is checked by the loop misclosure resulting for the levelling line:

$$e_{\Delta h} = \Delta H_{AB}\ (\text{forward}) + \Delta H_{BA}\ (\text{backward})$$

$$e_{\Delta h} = -24.5953 + 24.5972 = 0.0019\ \text{m.}$$

The classical levelling was performed according to the standard procedure, the measurements being made on another day and under atmospheric conditions that were different from the motorized case. The misclosure obtained according to the same calculation method was:

$$e_{\Delta h} = 0.002\ \text{m.}$$

For testing the production capacity of the motorized geometric levelling, an average going time was measured which was approximately 52 minutes for 1 km of traverse, the average measured distance between point and station being approximately 50 m. The total time used for each configuration in the station, including the travelling time, is approximately 2 minutes and 30 seconds. We need to state that the results depend on the abilities of the staff and the optimal correlation of the tasks of all the team members. In the case of the classical geometric levelling, the average going time was approximately one hour for 1 km of traverse.

The conclusions can only be generalized with a certain degree of approximation, since the measuring process was performed in an experimental phase, on a relatively small section of the road.

For a project of expanding the levelling network in Iași County, a statistical analysis can be performed in a GIS programme regarding the total length of the roads, according to their positioning in or outside the built-up area, by categories of roads.

The levelling network for the outside the built-up area in Iași County would comprise about 700 new points at a distance of 2 km between them, 180 points for national roads and 520 points for county roads (Figure 8).

The estimated time for the works of motorized geometric levelling would be approximately 1,200 hours, which means about 200 days (half a year) working 6 hours/day.

Table 1 Height differences measured both ways

Distance between successive points	**Height differences forward ΔH (m)**	**Distance between successive points**	**Height differences backward ΔH (m)**
1	*2*	*3*	*4*
1	0.7848	1	3.1837
2	-1.4017	2	2.1661
3	-3.6666	3	2.0649
4	-4.4327	4	2.2866
5	-4.1582	5	2.0849
6	-2.0300	6	4.1598
7	-2.3403	7	4.4403
8	-2.0495	8	3.5995
9	-2.1122	9	1.3794
10	-3.1924	10	-0.7679
ΔH_{AB}	**-24.5953**	**ΔH_{BA}**	**24.5972**

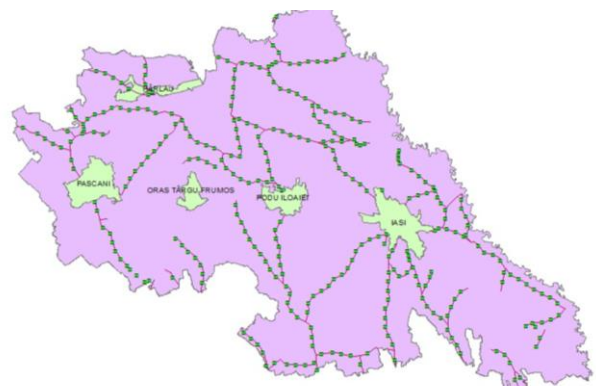

Fig. 8 The levelling network expanded on the national and county roads outside the built-up area in Iasi County

4. Conclusions

The main advantages of using the motorized geometric levelling are:

- The time it takes to perform the measurements is shorter than in the case of classical levelling.
- The transportation of the measuring instrument and of the rods is automated, a maximum efficiency being obtained when the operators never leave the car during the measurements.
- The working conditions are improved, as almost all the operations are performed in the vehicles, which diminishes the fatigue of the staff.
- The method ensures increased safety for the operators, as they are protected by their being inside the car and by the numerous warning signs on and around the vehicles.
- Measurements can be performed throughout a season and throughout the work day, even when the weather is

unfavourable (wind, low temperatures etc).

- The method offers the opportunity to raise the line of sight, the effect being the diminishing of the influence of vertical refraction, and the consequence is that the measured distances become more uniform.
- The use of motorized geometric levelling satisfies the precision requirements of all types of projects, from determinations in the first order national network to the lower order common works.

A disadvantage of using motorized geometric levelling could be the production cost, which is higher than in the case of classical levelling, as it needs investments in the gripping systems, the modification and adjustment of the vehicles and accessories and it consumes resources during the measurements. Motorized levelling needs a well-trained, experienced team. Using sophisticated equipment for motorized levelling needs more planning and organizing than in the case of conventional levelling. Still, the more thorough the organization is, the higher the productivity and the lower the execution cost will be.

In the case study, the work procedure was half motorized, as the vehicle on which the bar code rod was placed did not have an automatic device for lowering it to the ground and the turtle was manually placed by the operator. As no major changes could be performed on the used vehicles, a gripping system for the tripod and the rods needed to be developed without affecting the structure of the car.

The results, although they offer a precise levelling, according to the technical specification of the used instrument (± 2 mm/km), need to be confirmed by an expansion of the works on longer itineraries and under different relief and atmosphere conditions. For increasing the precision, the recommendation is to use better electronic levelling instruments and for increasing the degree of automation, it would be useful to work with a robot levelling instrument and to check the measurements on-site, in real time, with a computer.

If, for natural reasons (very slanted slope), the motorized geometric levelling cannot be used, the motorized trigonometric levelling needs to be used, with its specific equipment and methods.

The production capacity of the motorized geometric levelling recommends it for the implementation of this technology for redetermining the national levelling network in Romania, together with the GNSS simultaneous determination of some of these points in order to get a precise quasigeoid model on the Romanian territory.

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