THE EVOLUTION OF OPTICAL AND OPTOELECTRONIC DISTANCE MEASUREMENT TECHNIQUES IN APPLIED TOPOGRAPHY

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Abstract

Over the years, measurement techniques have evolved because of the increasing complexity of engineering works and execution speed while adapting to global economy needs. Contrary to angle measurements, distance measurements have involved a number of technical errors that could be diminished through technology advancement and innovative methods. In this paper we try to present a gradual evolution of these types of measurement methods and technologies. The complexity of these technologies has significantly decreased their execution time and increased their accuracy of determination reaching a few millimeters in certain situations. Thus, we set off from the first types of devices which determined distances around the 15th century and reach photogrammetry techniques of determination and the total smart station. This station uses methods and technologies which increase the speed and accuracy of the determination. We also present 3D scanning laser technology which is among the latest findings in the research area. Finally, we show different advantages and disadvantages of each of these presented methods.

Keywords: applied topography, optoelectronic distance measurement, 3D scanning laser, photogrammetry techniques

At the beginning of the 17^{th} century the telescope was invented to be used mainly in astronomy. At the same time, it also began to be associated with various topographic instruments, leading to the invention of the modern theodolite by Thomas Sisson (Miles 1999) in 1725, a reticle being added to the telescope. Being also equipped with side rulers and mark scales (*figure 1*) it allowed an empirical determination and control of distances.

Figure 1 **Theodolite**
a) Modern b) Classic

At the mid 19^{th} century, Ignazio Porro invented the stadimeter that later equipped all modern theodolites (*figure 1a*). Thus, using a scale, two stadimetric wires engraved on the telescope reticle and the readings on the rod, we indirectly get the distance between two points.

MATERIAL AND METHOD

The continuous development of the optoelectronic instruments and technologies for measuring distances has lead to new approaches and uses of the national networks of control points, applicable in various fields like:

- Triangulation networks thickening allows the determination of longer distances using these technologies;
- The use and exploitation of engineering networks allows the study of the behavior in time of engineering works, the possibility of following the measurement and the interpretation of results in different ways

The optoelectronic measurements have had a large range of uses due to the new technologies that have provided the required accuracy, as follows:

- Laboratory determinations for industrial purposes

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- Constructing and monitoring buildings of vital importance (e.g. nuclear power plants)
- High accuracy technological lines (ship construction)
- Studies of landslides.

Unlike the measurements for the determination of horizontal or vertical angles, the distance measurement has required more laborious measures and methods since the measurement errors are more frequent and consequently, bigger.

RESULTS AND DISCUSSIONS

The invention of the optoelectronic measuring instruments or **Electronic Distance Measurement (EDM)** was possible after the World War II after the notion of radar transmission became popular.

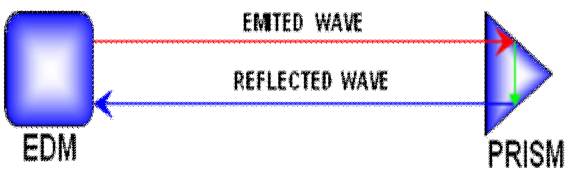

Figure 2 **Electronic Distance Mesurement – EDM**

The term geodimeter is short for Geodetic Distance Meter (*figure 1*) which was invented by the Swedish E. Bergstrand in 1948 and used for the first time in Canada in 1952. It uses the technique of measuring distances through light signals (1). The first device of this kind weighed 100kg and it took about 2 to 3 hours to determine a distance. It was mainly used by the army for night measurements up to 30 km and having a determination accuracy of 1/300,000.

Figure 3 **Geodetic Distance Meter – NASM-2A built by swedish from AGA**

Figure 9 presents the 4D model of the same Swedish maker AGA. On the left there is the control panel and on the right there is its optical part.

Weighing half of the previously mentioned model, it can measure distances up to 5 km. The loss of weight had a negative effect on the distance which decreased about six times, consequently the price decreased too, to 5,000 dollars down from 25,000 dollars, the price of its predecessor.

Figure 4 **Geodetic Distance Meter –Model 4D built by AGA**

The next model, Model 6, was built in 1967 (*figure 5*) and was more similar to the classical devices but it still did not have their weight nor reliability. This model weighed 17 kg, in 1968 being built the first model which replaced the light waves with laser beams.

The characteristic of the reception prisms (*figure 6*) is that the reflected beam is always transmitted in the same direction regardless the direction of the incident beam, improving greatly the measuring accuracy.

In 1957 T.L. Wadley made the first tellurometer MRA1 that did not use the light waves but the radio-electric waves which are less dispersed than the former.

Figure 5 **Geodetic Distance Meter – Model 6 Geodimeter with batery of nine prisms**

Modern technology has allowed rapid development of the measuring instruments and devices and especially the ones for measuring the distances optically. Thus, the tachymeters (*figure 1*) have known considerable improvement of measuring performance due to these technologies that allowed shorter measuring times and greater accuracy and consequently a more frequent use in current practice.

a. b. c.

Figure 6 **Types of tachometrics**
a) Trimble 3300, b) Elta 13C , c) Laica TCR 307

Their evolution has lead in time to the use of the term Total Station (*figure 7*) due to a series of features like:

- The possibility of automatic storage of data on internal or external memory
- The implementation of special programs which allow specific topographic measurements used in engineering
- The automatic processing of the field data using the implemented programs
- The transformation and presentation of the results in graphical formats – CAD

The measuring precision can reach 2 – 5 mm in 2 – 5 seconds, depending on the model.

Figure 7 **Laica Total Station – TPS 1200+**

Lasergrammetry is a method of mathematical digitization of three dimensional objects with high usage potential due to this possibility of 3D rendering.

The laser uses the infrared technology; the infrared waves are electromagnetic waves of a greater wave length than that of visible light, but shorter than that of microwaves.

The scanner-laser (Barras V., 2013) is a portable device (*figure 1*) measuring in three dimensions that uses laser technology to create 3D representations of objects of detailed shapes and dimensions and complex geometries.

Figure 8 **Scaner Laser 3D**

This technology is mainly used by the engineers (Popia M., 2013) and architects and replaces the traditional techniques with a powerful tool of 3D rendering that allows gathering more complex data in a shorter time, leading to lower costs of greater, more complex projects.

Having a hight measuring of accuracy (1 mm) this technology can be used to digitalize complex elements like apartment buildings, historical buildings and even factories. The amount of data recorded is extensive and the scan distance is limited to 20-40 m.

3D laser scanning provides among other things:

- 3D visualization and manipulation of digitalized objects (buildings, land areas, installations)
- Accurate determination of distances between identified points
- Volumetric modeling of buildings using shape recognizing functions.

There are also other advantages brought by 3D laser scanning technology that are worth mentioning:

- Various types of surveys
- Elimination of survey errors caused by the omission of certain elements
- 3D digital files of high precision
- The measurement is done faster so the whole process is less time consuming

The satellite technology (Global Navigation Satellite System – GNSS) is ideal for the determination of spatial coordinates of points and consequently of distances (Andrei C., 2013). This method is useful when the density of points is not that great, for instance, for distances of 50 – 100 m on a scale of 1:5,000 or 1:10,000. If the terrain allows it, the measurements can be done using an off-road vehicle equipped with a mobile receptor that optimizes the automatic processing of the registered data in real time.

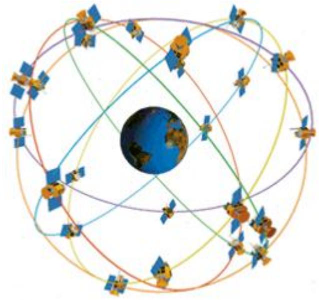

Figure 9. **Global Navigation Satelite System – GNSS**

The Total Smart Station (*figure 10*) is a mixture of GNSS receptor and Total Station, having superior features for a very accurate and fast determination of the coordinates of the topographic points.

The smart station has the following advantages:

- Is very precise and quick
- Saves time and money
- Increases productivity and profits

Figure 10 **Leica Viva Smart Station**

Photogrammetry is the science or technique that deals with the acquisition of reliable information about the natural environment or physical objects through recording, measuring and interpreting data starting from photographic aerial images taken with special technologies and devices.

Due to the complexity of the systems used to get these photographs, this technology is very expensive, but, at the same time, it is the fastest to use on large areas (Albi E., 2006). Security institutions like the army, make use of this technology extensively, using drones (planes without a pilot – *figure 11*) to avoid the danger of spying or surveillance accidents.

The first photogrammetric surveys were done by Aimé Laussedat (1848-1850). The technique was improved by Albrecht Meydenbauer (1834-1921) who founded the Royal Prussian Photogrammetry Institute.

In Romania, the first photograph from a hot-air balloon was taken by the officer Vaitoianu (1889), the first photograph from a plane being taken by Aurel Vlaicu (1901). The following table highlights some advantages and drawbacks of lasergrammetry and photogrammetry in comparison.

Figura 11 **Photogrammetry**
Aerian picture taken by a drone

Table 1 .
Advantages and disadvantages for lasergrammetrie and photogrammetry

	Photogrammetry	**Lasergrammetry**
Cost	accepable	Very expensive
Taking and recording the picture	Medium picture taking time Requires good weather conditions	Short picture taking time Not necessarily
Storage space	Relatively small - several Go	large – tens of Go
Energy consumption	Great autonomy	Low autonomy
Data processing time	long	short
Accuracy	good	Very good – down to millimeters or tenths of millimeter
Scale	Indirect – post treatment	Direct on data acquisition

CONCLUSIONS

This paper presents a chronology of optical and optoelectronic distance measuring techniques. Thus, starting from the classic theodolite, we got to advanced technologies which integrated satellite technique with Total Station into one single device giving it great autonomy in doing the measurements through combining the classic and satellite methods.

In *table 2*, there is a synthesis of these aspects and the advantages and disadvantages of these technologies in chronological order.

Table 2.

Advantages and disadvantages for the presented methods and devices

Date	Method and devices		Advantages and disadvantages	
1720	Modern theodolite	Paralactic methtod with known base	Small distances Require additional calculations - indirect method Requires two devices or successive displacement of one	
		Paralactic methtod using bribery or stage	Readability depends on mira reading Require additional calculations - indirect method Requires two operators Small distances	
1960s	Total Station	Maintained wave	Without reflector	One operator Small distances – 100 m Accurate and fast
			With reflector	Two operators Large distances Frequency modulation required Accurate and fast
1980s		Pulsed wave	Without reflector	One operator Small distances Accurate and fast
			With reflector	Two operators High load Accurate and fast
1990s	GNSS		Accuracy and time measuring variables Drivable field measurements	
	Numeric photogrammetry		Long Post-treatment Finale date: Model 3D Accurate Need more pictures of the same data	
	Lasergrammetry		Fast post-treatment Very expensive Final Data: Model 3D Very accurate	
	Total Station	Robotic system	Idem station totale standard Traceability and automated detection prism	
		Preinstalled software	Allows efficiency scheduling for different implemented measurement techniques	
2005	Total Station + GNSS		Efficiently combines classical techniques with satellite measurement One or two operators – function of the complexity of the work	

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***** - AGA** Museum teem men: http://www.aga-museum.nl/page/aga-geo

***** - Leica** - http://www.leica-geosystems.com/en/index.htm