The Evolution of the Two Standards of Measure to the Present Day Electromagnetic Distance Measurements (EDM)

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Key words:

ABSTRACT

Distance measurement has developed through history from pre-Christian times when the basic unit was cubit up to the present-day use of automated distance measuring instruments by surveyors, which makes measurements rapid and easy. The accuracy of distance measurements depends, on the calibration of the measurement unit and since the modulation wavelength is used as a measurement unit in electronic distance meters, this wavelength has to be accurately established. Since most surveyors do not know the basic checks for calibration of today's EDM instruments they are not able to achieve the accurate results required. This paper looks at the origin and development of the two standards of measure to the present-day use of wavelengths of radiation for defining a standard; also step by step routine checks for the calibration of the EDM are provided.

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1. INTRODUCTION

"Unless you know where you are coming from, it is difficult, if not impossible, to know where you are going". This old adage guides us to understand that to appreciate today's "push-button" and "black box" technology in combination with integrated software packages which make survey measurements far easier and to know what to achieve in the future, one needs to know the development of the standards of measure to the present day EDM. In order to understand what a standard of measure is, one must know something of its history and evolution. Although, the yard (or the foot) as a unit measure stretches back farther into ancient past, it is clear that they (i.e. both yard and meter) had their origin, as did most other ancient units, in human body, but the foot in any one country varied from those of its neighbors and there was direct relation between them. For instance, the Royal foot can be found quoted as equal to 13.75 present inches, the Amsterdam foot as 11.41 inches and the Natural foot as 9.8 inches (Smith, 1969).

The surveyor as a professional has to work in an optimal way according to the quality of the work, the date for completion of work, and the optimum cost and benefit of work. The realization of these goals demands not only knowledge and use of adequate measurements and calculation methods, but also the use of appropriate equipment for each specific project. He is fundamentally concerned with the measurement of horizontal and vertical distances and angles and, more recently, with direct positioning. These, then, are used in various combinations in all areas of survey. Linear measurements can be achieved by direct comparison measurement with a tape, either fully supported on the ground or suspended in catenary; optical distance-measurement methods by remote angular observation on a variable- or fixed-based length held horizontal or vertical, such as in tacheometry, stadia, or subtensing; and electromagnetic distance instruments utilizing the travel time of radio or light waves converted to distance. To the surveyor, the word distance usually refers to the horizontal length between two points projected onto a horizontal plane.

With all the present-day focus on the electronic distance-measuring instruments, it would seem appropriate to trace the origin, evolution and development of the two standards, the yard and the meter. This paper looks through the evolution and the development of the standards to the present day EDM, regulations and standards for its calibration and use as tool of measuring distance.

2 UNITS OF LINEAR MEASUREMENT

Several methods are used to measure distances. They range from rather inaccurate estimates to very precise instrumental procedures. Most early measurement units were derived from physical dimensions associated with parts of the human body. For example, the cubit, digit, palm, hand, span, foot, yard, pace, and fathom can be traced to human anatomy. Many others, such as the rod, pole, perch, chain, furlong, mile, and league are extensions of these basic units (See table 1).

Table 1 Units of Length.

Unit	Inches (in.)	Feet (ft)	Yards (yd)	Rods (rd)	Chains (ch)	Meters (m)
1 inch	1	0.08333	0.02778	0.00505	0.00126	0.02540
1 foot	12	1	0.3333	0.0606	0.01515	0.3048
1 yard	36	3	1	0.1818	0.04545	0.9144
1 rod	198	16.5	5.5	1	0.25	5.0292
1 chain	792	66	22	4	1	20.1158
1 mile	63 360	5280	1760	320	80	1609.35
1 meter	39.37	3.281	1.094	0.199	0.04971	1

Many old units have been discarded in favor of the basic ones, yard and meter. Much of the world has now converted to the meter-decimal system (SI units) as illustrated in table 2.

Table 2 Metric Units of Length.

Units	Micro-meters (µm)	Milli-meters (mm)	Centi-meters (cm)	Deci-meters (dm)	Meters (m)	Kilo-meters (km)
1 micrometer	1	0.001	0.0001			
1 millimeter	1 000	1	0.1	0.01	0.001	
1centimeter	10 000	10	1	0.1	0.01	0.00001
1 decimeter	100 000	100	10	1	0.1	0.0001
1 meter	1 000 000	1 000	100	10	1	0.001
1 kilometer			100 000	10 000	1 000	1

2.1 The Yard

The yard dates back to A.D. 960 when it was defined as an official standard yard by King Edgar as the length of a hexagonal brass rod kept at Winchester. During the reign of Ricahrd I (1189-1199), the yard was used in the measurement of land for tax purposes, it was even said that his officers had iron yard bars to help them in their tax collecting although at that time there were no subdivisions of yard.

In 1216 Richard I tried to standardize the width of cloth but this could not materialized until the time of Edward I (1272-1307), when the first table of relations appeared (see Table 3).

Table 3 Relations of units of measure.

Unit of Measure	Equivalent
3 grain of barley (dry and round)	1 inch
12 inches	1 foot
3 feet	1 Ulna
5.5	1 rod
(40 x 4) rods	1 acre

The Ulna in this table was a material primary standard made of iron in 1305 and which formed the basis of several subsequent standards. Even after this, however, there were still two " feet " coexisting in England for a long time. These were the British foot of approximately 12 inches and the Belgic foot of 13.2 inches. The latter became known as the "hard and handful" to distinguish it, but was made illegal by Henry IV (1439).

In 1490 a new yard standard in the form of a roughly subdivided octagonal bar was introduced by Henry VII. By 1588, however, a new half-inch-square brass rod standard yard, based on the bronze yard of Henry VII, which in turn was based on the Ulna of 1305, was approved by Queen Elizabeth I (1588-1603). This remained as the standard until 1824. Various sources gave various lengths for these old standards, but publication in 1798 gave the following relations:

36 inches of Henry VII standard yard of 1490 = 35.924 inches of *Troughton scale 1796.*

36 inches of Elizabeth I standard yard of 1588 = 36.015 inches of the *Troughton scale 1796*.

During the same year a brass standard based on the Elizabethan standard of 1588 was made for the Royal Society and had a value in terms of the *Troughton scale* of 35.99955 inches. A further standard, based on that of Elizabeth, was made in the form of a bronze bar 1 inch square by 39 inches long, with two gold plugs bearing fine marks. Legalized in 1824, it was quoted as 36.00023 inches of the *Troughton scale.*

In 1946 the Empire Scientific Conference proposed a redefinition of the yard as exactly 0.9144 m. This agree quite closely with the ratio found at the N.P.L. in 1947 of 1 meter to be 3.2808488 feet or 1 yard to be 0.9143975 meter. Further study revealed that the Imperial Yard could only be compared to 0.00002 inch whereas the meter permitted comparison to 0.000004 inch. As a result the adoption of metric units of measure was recommended.

2.2 The Meter

Within the period of six years i.e. 1792 to 1798, Mechain and Delabre surveyed the 9º 39' of arc Dunkirk to Barcelona, and as result the new standard meter measure was calculated in terms of the toise used by them. Even so, in the meantime there had been further uncertainty over whether to use the length of a second pendulum, a fraction of a parallel at the Equator or a fraction of the Meridian, but they did eventually agreed for the latter.

As the survey progressed, based on La Cailles's value of 1º of the meridian at 45º of 57027 toises, it was recommended that the meter be 443.443 Paris *lignes,* and a brass of this length was produced by Borda and Brisson. However, when the arc was finally completed in 1798 the Commission gave the relation as follows:

1 meter = 443.295 936 Paris *lignes* at 0º C, and a new scale was ordered from Lenuar, i.e.

1 meter = 513 0740 x 864 x 10^{-7} = 443.295 396 Paris *lignes* or

1 French foot = 144 *lignes* = 0.324 839 meter.

In 1865 Clarke came out with many comparison of the standards, the most notable results were as shown in table 4 below.

Table 4 Comparison of the Standards of Measure

Equivalent	**Yards**	**Millimeter**
The Yard	1.000 00000	914.391 80 mm
Y_{55} at 62ºF	0.999 99960	914.391 43
Ordnance Bar O_1 at 62ºF	3.333 33717	3047.976 16
Ordnance Bar OI_1 at 62ºF	3.3333 35432	3047.991 84
Ordnance Toise at 61.25ºF	2.131 66458	1949.176 60
Ordnance meter at 61.25ºF	1.093 74800	1000.114 20
Royal Society meter at 32ºF	1.093 60478	999.983 24
The toise	2.131 51116	1949.036 32
The meter	1.093 62311	1000.000 00

Since Ordnance toise T_o = Toise of Peru T + 153.42 x 10^{-6}
And T = 2.131 51201 Y_{55}
And the meter by definition is 443.296 *lignes* of the Toise of Peru, then:

Meter = 1.093 62355 Y_{55}

The value of the meter derived from the Royal Society Platinum meter was

Meter = 1.093 62446 Y_{55}.

In 1960, Cadmium (Cd) 114 was used to define the meter, then the laser was discovered. In 1973, the speed of light was connected to the meter, this was 100 times better than the previous measurements, bringing about the current definition of the meter as the length of the path traveled in vacuum within a time interval of 1/299 792 458.

3 THE ELECTRONIC DISTANCE MEASUREMENT (EDM)

The development of EDM has a close relationship with developments into the study of the nature of light and electronics in connection with finding the suitable standard of measure. The Michelson interferometer was first used to investigate the speed of light, and then it became obvious that it can help to measure distance. The problem of the type of light source was found in laser technology. Then the problem of choice of that will be consistent for distance frequency, various manufacturers choose from these three basic parts of electromagnetic spectrum as their carrier signal:

i. Instruments using radio signals of low frequency (wavelength of order 10^3 m to 10^2 m)
ii. Microwave radio signals of wavelength of order 10^{-2}
iii. Visible and infra-red light sources.

Generally, it was realized that low frequencies are always susceptible to providing low accuracies in distance measurement, thus high frequencies are always preferred as this gives high accuracies, it's propagation through the atmosphere has been found to be more stable. The wide range of EDM instruments currently available employ the technique of pulse echo or that of phase measurement using digital pulse counting. This consists of two basic signals, the carrier and the measurement signal, combined to form a modulated signal, which is then transmitted through the atmosphere to reflectors. These are usually manufactured such that reflected signal travels along the same path back to the EDM instrument. Without the knowledge of the fundamental checks of the EDM instrument it is very difficult of achieve accurate results.

3.1 Achieving Accurate Measurements

The wide range of EDM instruments currently available employ the technique of pulse echo or that of phase measurement using digital pulse counting. This consists of two basic signals, the carrier and the measurement signal, combined to form a modulated signal. This is then transmitted through the atmosphere to reflectors, which are usually manufactured such that the reflected signal travels along the same path back to the EDM instrument. The alignment of the reflector has been described as not being critical although precise alignment of measuring instrument is essential. This has been confirmed for a lot of weather friendly situations and the need to look into manufacturers assurance of being able to use these equipment in not so weather friendly situations need to be assessed by survey authorities and universities. For all these, to achieve accurate results depends on proper checks and calibration.

EDM calibration has been well presented on most standard texts, and baseline measurements can be undertaken on most Geomatic universities worldwide. In Ghana such baselines are not well established on the various campuses. The on-going research is trying to rectify this situation. Practically the authors whilst undertaking survey consultancies for various firms were able to use survey beacons established by the British in 1953 to check EDM distance measurement under the prevailing conditions thereby calibrating the EDM right in the field. It is interesting to note that the degree of accuracy was very high.

3.2 Fundamental Checks

The measurement of any distance is accomplished by comparing it to a multiple of a calibrated distance. In EDM instruments, the same comparison principle is used. That is, the calibrated distance is the wavelength of the modulation on a carrier (light or microwave).

The most fundamental routine checks are those recommended by manufacturers and these are most of the time related to survey specifications. To check the stability of the EDM instrument, it is very necessary to compare measurements on established baselines with known lengths (distance range from, 50m to 300m, see figure 1). These baselines should normally have one marked instrument station and three permanently mounted reflectors at typical distances for the usual working range of the particular EDM instrument.

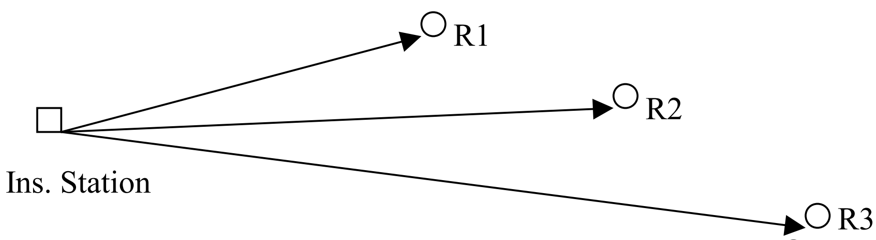

Fig. 1 Reference points for checks

The lengths of these baselines are always determined with more accurate distance meters before and after each full calibration. If the results from the above checks indicate significant difference for all the checked distances, it is recommended that the check be repeated very carefully. However, if the second comparison check confirms the results of the first, a change in the performance of the instrument or the positions of the pillars for the baseline are suspected. It is necessary to find out the cause of the change before using the instrument for any project.

3.3 Checks for the Additive Constant

In this case, a baseline of about 50 m consisting of at least 4 points a (see Fig. 2) aligned in the same horizontal plane must be set-out. The distance between the tripods must be a whole number of the unit length, ($U = \lambda/2$) of the EDM instrument.

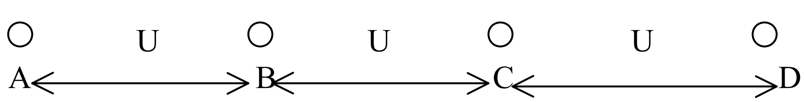

Fig. 2 Baseline for checks for Additive Constant

From the measurement of the six segments of the six segments AB,AC, BC, BD and CD the additive constant "a" is computed from equations:

$$AB + BC + CD - AD = -2a$$
$$AB + BD - AD = -a$$
$$AC+CD- AD = - a$$

With a final value of "a" from the mean of all three individual values. By analyzing the above results of check, it can be said that:

- If the new value for "a" is not significantly different from the old value, the changes detected by the previous check may come from the instability of the instrument station.
- If the new value for "a" is significantly different from the old value, the whole
- check should be repeated to confirm the new value (Anon., 1994)

4. CONCLUSION

Tracing the history of these measurement standards will in no doubt put the young Geomatic professional to understand how far we as geomaticans have got and to enable them to come up with innovative ideas as to the way forward.

There is no doubt about the fact that EDM has revolutionized the surveying profession. In the days of the optical-mechanical instruments the measurement of angles and distances by catenary measurements, the computations involved were laborious and time consuming, the EDM is quick to master, efficient, flexible and provides data security thus improving topographical mapping.

The problem of calibration and conditions under which these EDM instruments are used posses a problem. The good out of all this is, when properly used with all field conditions taken into account then the user will definitely come out with data that is free of errors. Trace ability of these standards of measure will always be of great interest to our button-pushing carefree young geomaticians. The aim here is for our youth to appreciate where we have got to and to take up the mantle and come up with more innovative ideas as to how to push the profession forward in this millennium.

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