Additional Comments About a Modified Theodolite Instrument: Conceptual Work

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Additional comments about a modified theodolite instrument : Conceptual work

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Abstract :

A proposed modified theodolite instrument is presented. The instrument concept, sequence of operation of measurements, and design plans are reported. The proposed instrument has a potential similar to metric photogrammetry in computing 3-D coordinates without physically touching the target point. A sliding graduated rod (arm) has been introduced to connect the upper and lower parts, each of which has a separate vertical vernier. The rod supports the theodolite head that can be extended upward an arbitrary distance, thus effectively providing a second position for the head. Appropriate angular measurements, together with the length of the extension (the rod) can be used to calculate the inaccessible distances. The instrument relies on simple trigonometric functions to measure the height of objects and the horizontal and slope distances, and to perform trigonometric leveling. Accuracy potential of the instrument has been presented based on the law of propagation of random error. The flow of operations for different measurement cases has been mathematically demonstrated. The instrument is anticipated to bypass the cost-effectiveness and technological bottlenecks between plane surveying and photogrammetric systems.

Introduction:

The theodolite is an instrument which is suited for angular measurements including both horizontal and vertical angles as well as performing trigonometric leveling. Currently, the instrument is available in various forms starting from the old models of verneir transit of accuracy about thirty seconds, and reaching the automatic digital or electric theodolite which have accuracy of better than 0.5 seconds and 1.0 seconds, respectively.

In conventional surveying practice, the location of any visible point at any height can be computed by measuring the elevation (or depression) angle and the horizontal distance to the point considered. Unfortunately, sometimes measuring distance faces challenges of obstacles such as rivers, sea, tree, or building. These obstacles sometimes cannot be physically removed and/or passed through or over. Thus, other instruments such as Electric Distance Measurement (EDM) or Total station are used for this purpose. A self-reducing Tacheometer (using a constant stadia interval factor), with the aid of a rod (leveling staff), might also be used in order to measure angles and distances with a relative accuracy of distance measurement better than $1/500$.

The measurement process involves observing the rod intercept from the image of the rod. For the use of the previous three instruments there is no need physically to pass between the two points in concern. Instead, the instrument setup at a convenient point while a reflector unit or a rod is placed at the target point for the aid of the EDM/ Total Station opt Tacheometer. The problem of observing vision and the prevention of direct measurement could be overcome by taking parallel lines at right-angle offsets. However, measuring distance and physically reaching target point are still essential in all these possibilities in order to compute the 3-D point location. This makes the 3-D point location produces inconvenient, costly, and time consuming.

using two sighting positions to get around the difficulty of inaccessibility is another alternative which could be used to find the location of a visible point. For example, the field artillery range finder might be used in order to find linear distances, but its measurement accuracy diminishes as length increases. Also, it is common surveying practice to move the transit to a second position at right angle to the original sighting line, say 5 to 10 meters away, to get the necessary triangle for distance calculation. An arbitrary surveying base line of two control points might also be constructed and the horizontal and vertical angles between the control points and the target could be measured. Then, point location of the target point could be found using the intersection geometry.

Photogrammetry has also been shown to be a tool for remote 3-D measurements, i.e. without touching the object being measured however, this process involves cameras, a calibration field for the cameras, images, data reduction and processing, and specialists in the area. Thus, for a limited number of objects points, it is not worthwhile and cost-efficient to use this technology to replace plane-surveying methods to find heights, distances, and 3-D coordinates.

This paper describes atheoritical framework for modified theodolite instrument. The proposed instrument is anticipated to have a potential similar to metric photogrammetry in computing 3-D coordinates without physically touching the target point. The instrument does not use any measurement aid such as reflector or rod. Instead, a human operator could operate the instrument by using the mechanism shown in the body of the paper for measuring height of objects, measuring vertical and horizontal angles, measuring horizontal and slope distances, and performing trigonometric leveling. The development of such an instrument is anticipated to bypass the cost-effectiveness and technological bottlenecks between plane surveying and photogrammetric systems.

Instrument concept

The basic components of the proposed instrument are similar to any other theodolite, with the addition of a lower part which is the contribution of this paper. The proposed instrument has two parts:

Upper part (note: the numbers between the parenthesis are referred to the number appear on figure 1 through 3. Missing numbers will appear in the lower part components): this part is exactly like any available theodolite with an extra sliding side mirror (3) and a separate graduation of the vertical angle vernier. The sliding mirror is used to help in measuring angles in case of critical target locations which require short instrument height. The graduation of the vertical vernier is used in order to measure vertical angles with respect to a rod axis connecting the upper and the lower parts. The vernier of the vertical angle is attached to the telescope with an angle graduation of 90 degrees always coincident with the direction of the rod, whereas the zero degree is coincident with the horizontal plane only when the instrument is leveled, ie unlike the conventional theodolite which measures vertical angles with respect to the plumb-line. The rod will be described later in the lower part of the instrument. This means that the 90 degree angle mark is not always coincident with the plumb-line, instead it coincides with a rod which could be tilted toward the target point direction. The upper part has all theodolite functions including optical rough sighting (1), foot-screws for leveling (2), base-plate of leveling (4), vertical vernier (5), air bubble (6), leveling unit (7), telescope (8), supporting arm (9), horizontal verniers (10), objective piece (12), tripod connection (13), eyepiece for reading the graduation (14), scaling vernier (15), telescope eye piece, telescope focusing ring, eye piece for optical plummet, slow motion for telescope tilt in horizontal and vertical planes, vertical and horizontal circles display for angles, micrometer knob for seconds, switching knob between horizontal and vertical circles display, clamps for fastening the instrument on a leveling base, clamping levers for horizontal and vertical setting clamps, and all other accessories.

The basic function of this upper part is to measure vertical angles with respect to the rod as a reference line as well as measuring horizontal angles.

b. lower part (note: the numbers between the parenthesis are referred to the number appear on figure 1 through 3): this part has a sliding rod (11), another vertical vernier scale (16) and scaling vernier (17), and two fixing plates which serve as fixers for the components of this part (18) and have grooves in order to permit sliding of a rod to pass through. This part is connected with the tripod (13). Two vertical scale verniers are attached to the outer sides of two plates with angle graduations always having 90 degrees in the direction of the plumb-line. the function of the scale verniers is to measure complementary vertical angle with respect to the plumb-line passes through the telescope vertical axis at the time when the rod sides to a convenient height for the human operator and the telescope is tilted to sight to the target point. An opening groove exists between the two fixing plates. A sliding scale (rod) is another component of this part.

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The rod connects the upper and the lower parts together and passes through the plates grooves opening it could also be used in order to measure the height of the instrument (HI).the rod could be of any length depending on convenience and the height of the human operator it has the capability to slide up and down, varying the distance between the upper and lower parts. When the sliding rod goes down, it goes through the torpid in order to control the convenient height of the instrument.

Figure 2 shows the components of the lower part. Combination of 3-D representations of the upper and lower parts as well as different views and main components of the instrument are shown in figure 3.

Sequence of operations and orientations

In order to determine the height of an object or the distance to the object of concern, it is essential to make the following measurements and computational procedures which are shown in figure 4:

1. Set up the instrument above a convenient selected point; i.e. centering and leveling of the instrument. It is worthwhile mentioning here that leveling procedd is important for the lower portion vertical vernier while it is not the case for the upper part vertical vernier; i.e. unlike a conventional theodolite.
2. Sight and focus the telescope to the target point and measure the vertical angle (say α) of the horizontal line of sight of the telescope to the point using the upper vertical vernier; i.e. vertical angle with respect to the plumb-line (fgure 4-a)
3. Slide the rod, which connect the upper and lower parts, vertically up to have a convenient distance of separation between the upper and lower parts. This distance would not be in any case greater than the human operator height. The rod is still coincident with the plumb-line and the telescope vertical angle still α (figure 4-b)
4. Tilt the rod in a clockwise or counterclockwise direction, keeping the telescope vertical angle with rod to be α, with a vertical tilt angle α measured on the vernier of the lower part of the instrument. The tilt will be clockwise if the height of the point in concern is lower than the height of instrument, while it is counter clockwise if it is higher. Notice that there will be a right-angle between the rod and the imaginary line that connects the target point and rotation center of the lower vertical vernier of the instrument (figure 4-c). the rod tilt will give a vertical angle measurement without changing the horizontal angle in either the upper or lower verniers; i.e. tilt will be in a plane.
5. Tilt the telescope; i.e. without tilting the rod, in order to target the point in concern. Thus, angle β shown in figure 4-c could be measured. It is worthwhile mentioning here that the vertical angle graduation of 90 degrees of the upper vertical vernier is always coincident with the direction of the rod; i.e, the rod (not the plumb line) is the vertical angle reference in the upper part. Consequently, angle θ will be $(180-\alpha-\beta)$. Computation of the angle θ using this could be simplified if a nomograph is prepared with input α and β.

The result of this procedure is a right angle triangle formed by the three point representing the centre of rotation of the lower vertical vernier, the center of rotation of the upper vertical vernier, and the target point. The rod length between the two verniers can be measured accurately, since the rod is graduated linearly. Consequently, trigonometry functions could be simply applied in order to find the missing angle ae well as the length in the triangle. After that, horizontal and slope distances, trigonometric leveling and measurements can be easily found as well be seen in the next section.

Computation Concept

The measured rod length and the vertical angle θ give an indication of the scale for the horizontal and slope distance values between the setup point of the theodolite and the target point. The smaller the angle θ and the longer the rod, the stronger will be the intersection geometry at the target point of the two optical rays generated from the two telescope positions; i.e. the upper and lower positions due to the effect of the rod length. Consequently, the accuracy of measurements is expected to be highly correlated to the values of both rod length and angle θ.

As shown in figure 4, for target point A, rod length EC, and a theodolite at point C, the slope distance AC could be found as $(CE)\tan\theta$. Consequently, knowing the vertical angle α, read by the lower vernier (figure 4-a), the horizontal distance of AC; i.e. CG, is found to be $(AC)\cos\alpha$. Furthermore, the difference in elevation between the center of the lower vernierA will be $(AC)\sin\alpha$. Nomograph charts could be developed in order to quantify AC, CG, and the difference in elevation. Input for these nomographs are the rod length, angle , and angle θ.

Propagation of Random Errors

If the estimated standard errors; i.e. precision measures, of angle θ and the rod length are σ_θ and σ_{CE} respectively, then the precision of the computed length AC; i.e. σ_{AC}, could be estimated from the low of propagation of random errors.

$$\sigma_{AC}^2 = \left(\frac{\partial F}{\partial CE}\right)^2 \sigma_{CE}^2 + \left(\frac{\partial F}{\partial \theta}\right)^2 \sigma_\theta^2$$

Where the function $F = (CE)\tan\theta$

Two similar equations could be derived using the same concept in order to estimate precision of the horizontal distance and of the elevation difference.

Using the previous equation, for a typical situation, say for a rod length of about 1 meter and a measured slope distance of about 100 meters; i.e. θ is about 89.43 degrees, using estimated standard errors for rod length and angle measurements to be 1 mm and 5 seconds (2.42×10^{-5} radians), respectively, the computed standard error of the slope distance will be about 10 cm. if the rod length increased to about 1.20 meter and the measured slope distance decreased to 50.0 meter; i.e. θ is about 88.63, the computed standard error of the slope distance will be decreased to about 4.2 cm. further, increasing the measurement precision by enhancing measurement capabilities of the instrument; i.e. decreasing the estimated standard errors for rod length and angle measurements, will decrease the computed standard error of the slope distance. For example, for θ equals 88.63 degrees, rod length equal 1.2 meter, amd estimated standard errors for rod length and angle measurements are 0.5 mm and 2 seconds (9.69×10^{-6}) respectively, the computed standard error of the slope distance will be about 201 cm.

Measuring cases

This section shows the measurement procedures and computations of height, elevation difference, and distance using the developed instrument for different target configurations. The configurations include:

1. Object having its base at the same level as the theodolite set-up point.
2. Object having its base at the same level as the theodolite set-up point with an obstacle that prevents stance measurement using conventional methods.
3. Objects having its base and elevation of hight point below the theodolite horizontal line of sight.
4. Objects having its base and elevation of highest point above the theodolite horizontal line of sight.
5. Objects having its base below the theodolite horizontal line of sight, whereas the elevation of the highest point is above the theodolite horizontal line of sight.

Case 1 is the only case in which the object height could be found using conventional theodolite if the instrument height is known. In the other cases the object height canot be found using a conventional theodolite unless the horizontal distance between the theodolite and the object is known. The following sections discuss finding object height, elevation difference, and distance for each of the previous mentioned cases using the proposed instrument.

Conclusion

The development of such an innovative instrument will facilitate the measurement procedures to locate 3-D point positioning without the need of physically reaching the object being measured. Other by-product measurements such as areas and volumes might also be expected to bridge the technological gap between photogrammetric stereovision techniques and conventional plane-surveying instruments.

One of the essential requirements of using this instrument is the development of tables or nimographs to solve the measurement equations. This is anticipated to reduce the time required for measurement. Accuracy assessment factors such as rod length and intersection angle at the target point also play major factor in convincing users to employ the present instrument. Equipping the instrument with electronic angle measurement potential rather than transit mechanical procedures will give the instrument suitability and convenience.