Surveying I – Practical 12

Orientation of the instrument on a known station

In the previous practical, the first and second fundamental tasks of surveying were introduced. If we have a known station and are able to find the horizontal distance from our station to an unknown point and the whole circle bearing (WCB) from the station to the unknown point, we can compute the coordinates of the unknown point.

One problem with this approach is that the WCB between the station and the unknown point cannot be measured directly using an angle measuring instrument (theodolite or total station). In order to measure it, we would have to be able to precisely find the direction of the +N axis of our coordinate system at the station and measure the angle between that direction and the direction to our unknown point. As this approach is unfeasible in practice, we use an indirect method of connecting the mean directions (MD, measured using the theodolite/total station) to the WCBs. This procedure is called the orientation of the instrument.

Orientation using a single orientation target

The MD measured by the instrument is the horizontal angle between the zero mark of the instrument's HZ circle (marked by the blue dash-dot line) and the direction between the station and the unknown point. The WCB is the clockwise angle between the +N of the coordinate system and direction to the unknown point. The difference between the two is called the orientation angle and is denoted by z (red angle in the figure below). If we can find the value of z, we can add it to the measured MD of the unknown point and compute its WCB.

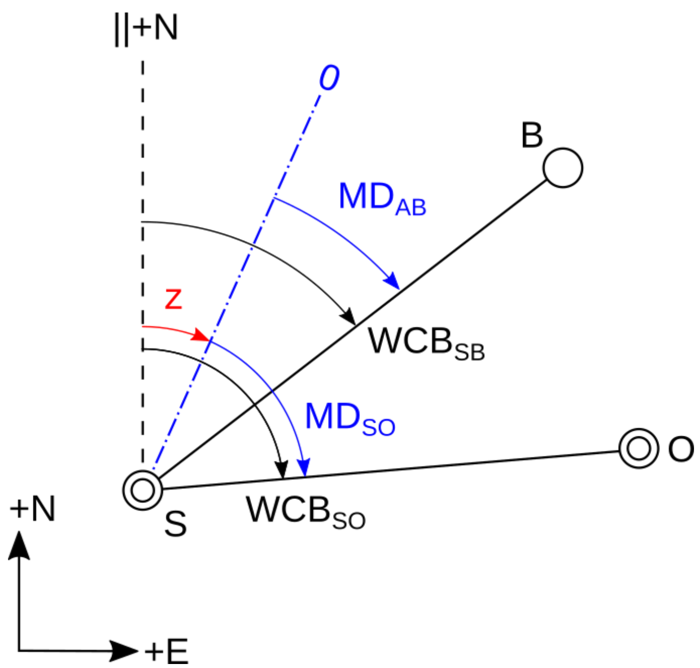

Figure 1. Connection between the orientation angle, the mean direction and the WCB.

In order to carry out the orientation and find the value of z, we have to be able to measure to **another known point (point with known coordinates)** from our station. Let this point be denoted by O. This is called an orientation target. These targets are usually tall structures or buildings that can be easily seen and identified from a larger distance (church towers, radio towers etc). As both the station and the orientation target are known points, we can use the II. fundamental task of surveying to find the WCB between the two points (WCB_{SO}). Apart from WCB_{SO}, we can use our instrument to measure the MD from the station to the orientation target (MD_{SO}). As seen in the figure above, the z angle can be computed with the following formula:

$$z = \mathrm{WCB}_{SO} - \mathrm{MD}_{SO}$$

in other words, we have to subtract the mean direction to the orientation target from its whole circle bearing. The value of the orientation angle z is constant for a station, as long the horizontal circle inside the instrument is not rotated. If we have to repeat the setting up or rotate the circle for some reason, the orientation has to be carried out again.

From the known orientation angle and the mean direction, we can compute the WCB between the station and the unknown point:

$$\mathrm{WCB}_{SB} = \mathrm{MD}_{SB} + z$$

Using the WCB and the horizontal distance between the station and the unknown point, we can compute the coordinates of the unknown point from the I. fundamental task of surveying.

Orientation using multiple orientation targets

To avoid errors due to incorrect measurements to the orientation targets, incorrect identification of the orientation target, movement of the orientation targets (and therefore change in their coordinates), more than one orientation target is used for the computation of the final value of z. The orientation angle computed from measurements to multiple targets is called the mean orientation angle ($\bar{z}$).

Let’s suppose that we have 3 orientation targets (O1, O2 and O3) that can be sighted from our station. We have measured mean directions to all of them (MD_{SO1}, MD_{SO2} and MD_{SO3}).

1. First, we compute the WCBs and the distances to each of the orientation targets using the II. fundamental task of surveying:

$$\mathrm{WCB}_{SO1}, \quad d_{SO1} = d_1$$

$$\mathrm{WCB}_{SO2}, \quad d_{SO1} = d_2$$

$$\mathrm{WCB}_{SO3}, \quad d_{SO1} = d_2$$

2. We compute an orientation angle using each orientation target. This will result in three different orientation angles:

$$z_1 = \mathrm{WCB}_{SO1} - \mathrm{MD}_{SO1}$$

$$z_2 = \mathrm{WCB}_{SO2} - \mathrm{MD}_{SO2}$$

$$z_3 = \mathrm{WCB}_{SO3} - \mathrm{MD}_{SO3}$$

   If any of the orientation targets have incorrect coordinates or were misidentified during the measurements, we will have an outlier in the z values. This z value can then be omitted when computing the mean orientation angle.

3. We find the value of the mean orientation angle ($\bar{z}$) by computing the weighted average of the individually computed z values using the distances to the orientation targets as weights:

$$\bar{z} = \frac{\sum_{i=1}^{n} z_i \cdot d_i}{\sum_{i=1}^{n} d_i} = \frac{z_1 \cdot d_1 + z_2 \cdot d_2 + z_3 \cdot d_3}{d_1 + d_2 + d_3}$$

   Using the distances as weights means that if an orientation target is farther from the station, the orientation angle corresponding to that target will contribute more to the mean orientation angle. As farther targets can usually be sighted more precisely, this method of calculation seems reasonable.

Calculated example for the orientation

We set up our station on point 3001 and measured the mean directions to the orientation targets (101-104) and an unknown point 3002. We also measured the horizontal distance between the station and the unknown point. Our task is to compute the coordinates of the unknown point.

The coordinates of the station and the orientation targets are given in the table below:

Point ID	Easting [m]	Northing [m]
3001	4 123.57	8 746.35
101	4 474.04	9 288.13
102	3 438.79	7 872.47
103	3 397.59	9 626.58
104	5 019.71	8 198.53

The measurements are contained in the following table. This table can be used for the computation of the orientation:

Station	Target	Mean direction	Orientation angle / Mean orient. angle	WCB	Distance [m]
3001	101	147-45-26			
	102	332-57-00			
	103	75-20-17			
	104	236-17-33			
	3002	10-47-50			1346.53

1. First, we have to compute the WCBs and the distances from the station to the orientation targets and fill them in the table. It is recommended to use the POL function on the calculator. (Don't forget to add 360° if the angle is negative.)

   As the distance to the unknown point measured with cm precision, we can give our computed distances with cm precision as well. As a matter of fact, it will not modify the end result of our computation.

Station	Target	Mean direction	Orientation angle / Mean orient. angle	WCB	Distance [m]
3001	101	147-45-26		32-53-54	645.26
	102	332-57-00		218-04-57	1110.22
	103	75-20-17		320-29-08	1140.99
	104	236-17-33		121-26-16	1050.32
	3002	10-47-50			1346.53

2. We can compute the orientation angles from each orientation target by subtracting the mean directions from the WCBs.

Station	**Target**	**Mean direction**	**Orientation angle / Mean orient. angle**	**WCB**	**Distance [m]**
3001	101	147-45-26	245-08-28	32-53-54	645.26
	102	332-57-00	245-07-57	218-04-57	1110.22
	103	75-20-17	245-08-51	320-29-08	1140.99
	104	236-17-33	245-08-43	121-26-16	1050.32
	3002	10-47-50			1346.53

The largest difference between two orientation angles is a little bit less than one arc minute (computed from 102 and 103). We could consider omitting the orientation angle computed from 102 as the remaining ones would seem to be more in line with each other. This choice always depends on the given situation and accuracy requirements. In the case of our example, we will use all four of the orientation angles to compute the weighted average.

3. To compute the mean orientation angle, we have to calculate the weighted average of the orientation angles using the distances as weights. To make the computation easier, we can subtract 245-07-00 from every orientation angle, calculate the average and add it back at the end. (For example, if we subtract 245-07-00 from the first orientation angle, we are left with 88 arc seconds.)

   For the weights, we are using the distances between the orientation targets and the station. To further simplify the calculation, it is enough to use the distances in km units with 0.1 km precision. (For example, the first distance 645.256 becomes 0.6 km.)

$$\frac{88'' \cdot 0.6 + 57'' \cdot 1.1 + 111'' \cdot 1.1 + 103'' \cdot 1.1}{0.6 + 1.1 + 1.1 + 1.1} = 89.97''$$

   If we add this value to the previously subtracted 245-07-00 and round it to arc seconds, we find that:

$$\bar{z} = 245\text{-}07\text{-}00 + 89.97'' = 245\text{-}08\text{-}29.97 \approx 245\text{-}08\text{-}30$$

Station	**Target**	**Mean direction**	**Orientation angle / Mean orient. angle**	**WCB**	**Distance [m]**
3001	101	147-45-26	245-08-28	32-53-54	645.26
	102	332-57-00	245-07-57	218-04-57	1110.22
	103	75-20-17	245-08-51	320-29-08	1140.99
	104	236-17-33	245-08-43	121-26-16	1050.32
	3002	10-47-50	245-08-30		1346.53

4. By adding the mean orientation angle to the mean direction of the unknown point, we can find the WCB between the station and the unknown point (don't forget to subtract 360° if the resulting angle is greater than 360°):

$$\text{WCB}_{3001-3002} = \text{MD}_{3001-3002} + \bar{z} = 10\text{-}47\text{-}50 + 245\text{-}08\text{-}30 = 255\text{-}56\text{-}20$$

Station	Target	Mean direction	Orientation angle / Mean orient. angle	WCB	Distance [m]
3001	101	147-45-26	245-08-28	32-53-54	645.26
	102	332-57-00	245-07-57	218-04-57	1110.22
	103	75-20-17	245-08-51	320-29-08	1140.99
	104	236-17-33	245-08-43	121-26-16	1050.32
	3002	10-47-50	245-08-30	255-56-20	1346.53

5. The coordinates of point 3002 can be computed using the I. fundamental task of surveying:

$$E_{3002} = E_{3001} + d_{3001-3002} \cdot \sin(\text{WCB}_{3001-3002}) = 4123.57 + 1346.53 \cdot \sin(255\text{-}56\text{-}20) =$$
$$= 2817.386 \approx \mathbf{2817.39\ m}$$

$$N_{3002} = N_{3001} + d_{3001-3002} \cdot \cos(\text{WCB}_{3001-3002}) =$$
$$= 8746.35 + 1346.53 \cdot \cos(255\text{-}56\text{-}20) = 8419.202 \approx \mathbf{8419.20\ m}$$