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# An investigation into the accuracy of the direction of the qibla in three historical mosques in Edirne, Turkey

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**Abstract:** For all Muslims it is important to pray in a specific direction, this is known as the qibla. The qibla direction of a mosque is generally determined using the qibla azimuth angle and qibla bearing angle which are calculated from the geographical coordinates of the Ka'ba Mosque in Mecca, Saudi Arabia and the place where the mosque is built. The door which is placed in the gallery of a minaret usually shows the qibla direction. In order to determine the accuracy of the direction the two horizontal edge coordinates of the door are required. This study has two important theoretical aspects. One concern measuring the qibla azimuth angle and qibla bearing angle and the other is related to the qibla direction shown by the minaret door. An experimental technique was carried out on the minaret doors of three historical mosques (Selimiye, Ancient and Three gallery of minarets Mosques) in Edirne, Turkey. The country coordinates of the corner points of each mosque were transformed into geographical coordinates, the qibla azimuth angles and the qibla bearing angles were calculated. The differences between the calculated qibla bearing angles and the qibla bearing angles shown by each door of the three mosque's minarets are examined and interpreted. This type of study has not been performed in Turkey and also has importance for archaeological work

**Keywords:** average of absolute errors, meridian convergence, qibla azimuth angle, qibla bearing angle, resection method

**Abstrak:** Bagi seluruh umat Islam, penting untuk beribadah ke arah tertentu, yang disebut kiblat. Arah kiblat suatu masjid pada umumnya ditentukan dengan menggunakan sudut azimuth kiblat dan sudut arah kiblat yang dihitung dari koordinat geografis masjid Ka'bah di Mekah, Arab Saudi dan tempat dibangunnya masjid tersebut. Pintu yang ditempatkan di galeri menara biasanya menunjukkan arah kiblat. Untuk menentukan keakuratan arah diperlukan dua koordinat tepi horizontal pintu. Penelitian ini memiliki dua aspek teoretis yang penting. Pertama menyangkut pengukuran sudut azimuth kiblat dan sudut arah kiblat, dan yang lainnya berkaitan dengan arah kiblat yang ditunjukkan oleh pintu menara. Teknik eksperimental dilakukan pada pintu menara tiga masjid bersejarah (Mesjid Selimiye, Ancient dan Three gallery of minarets) di Edirne, Turki. Koordinat negara titik sudut masing-masing masjid diubah menjadi koordinat geografis, sudut azimuth kiblat dan sudut arah kiblat dihitung. Perbedaan antara sudut kiblat yang dihitung dan sudut kiblat yang ditunjukkan oleh setiap pintu tiga menara masjid diperiksa dan ditafsirkan. Jenis penelitian ini belum pernah dilakukan di Turki dan juga penting untuk pekerjaan arkeologi.

**Kata Kunci:** konvergensi meridian, metode reseksi, rata-rata kesalahan absolut, sudut arah kiblat, sudut azimuth kiblat

## Introduction

For all Muslims it is important to pray in a specific direction, this is known as the qibla. This direction is generally determined using the qibla azimuth angle and qibla bearing angle which are calculated from the geographical coordinates of the Ka'ba Mosque in Mecca, Saudi Arabia and the place where the mosque is built. A lot of the studies were performed about this topic (the definition of The Qibla direction, the history of Qibla direction, the fundamental source of law in facing the Qibla) (Grafarend, 1978; Doyle, 2018; Ilci et al., 2018; Saksono et al. 2018; Ikbal, 2019; Hamdanı et al., 2020). In mosques the door which is placed in the gallery of a minaret usually shows the qibla direction. In order to determine the accuracy of the direction the two horizontal edge coordinates of the door are required. This study has two important theoretical aspects. One concerned measuring the qibla azimuth angle and qibla bearing angle and the other is related to the qibla direction shown by the minaret door. An experimental technique was carried out on the minaret doors of three historical mosques in Edirne, Turkey. The country coordinates of the corner points of each mosque were transformed into geographical

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coordinates, the qibla azimuth angles and the qibla bearing angles were calculated. The differences between the calculated qibla bearing angles and the qibla bearing angles shown by each door of the 3 mosque's minarets are examined and interpreted.

## Materials and Methods

1. Calculating the "qibla azimuth angle" and "qibla bearing angle"

The qibla azimuth angle (A) is the angle between a base line on the meridian direction passing through a point where the mosque will be built and the direction line that the point of interest connecting the Mecca (Figure l).

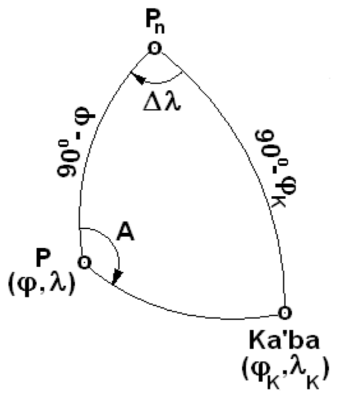



Figure 1. The qibla azimuth angle (A) on the P point

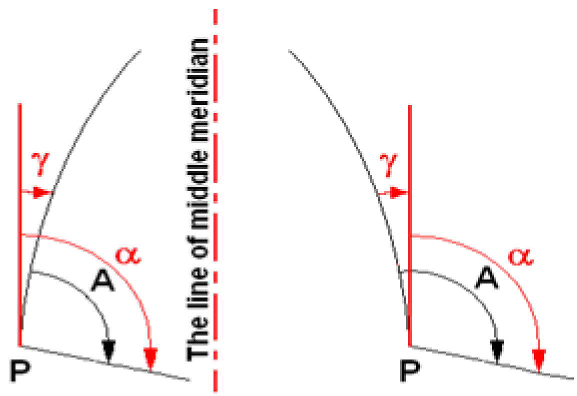



Figure 2. Obtaining the qibla bearing angle (α) according to the meridian vertical coordinate system

After determining the geographical coordinates (φ,λ) of the P point that will show the qibla direction, the geographical coordinates ($\varphi_K$ =21° 24', $\lambda_K$ =39° 44') of Ka'ba in Mecca in Saudi Arabia are considered. The qibla azimuth angle can be calculated using the Cotangent formula, Gauss semi angle formula, Neper formulas and series (Mackie, 1971; Müller and Eichhorn 1977; Grafarend 1978; Vanicek and Krakiwsy 1992). The Cotangent formula (1) is usually used in the calculation of qibla azimuth angle since it is easy to apply.

The qibla azimuth angle (A) is calculated with the following equation taking $\Delta\lambda = \lambda_K - \lambda$ from Figure 2.

$$A = \arctan\left(\frac{\sin\Delta\lambda}{\tan\varphi_K\cos\varphi - \sin\varphi\cos\Delta\lambda}\right) \qquad (1)$$

The qibla bearing angle (α) on the meridian rectangular coordinate system is calculated using the following equations with the A azimuth considering meridian approach angle (γ) (Figure 2). If the P point is on the left of segment middle meridian.

$$\alpha = A + \gamma \qquad (2)$$

If the P point is on the right of segment middle meridian

$$\alpha = A - \gamma \quad (3)$$

The meridian approach angle is calculated with the following equation considering the segment middle meridian ($\lambda_o$) and $\Delta\lambda' = \lambda - \lambda_0$ (Grafarend, 1978; Vanicek & Krakiwsy 1992).

$$\gamma = \arctan(\sin\varphi \tan\Delta\lambda') \quad (4)$$

2. Calculation of the coordinates of points belonging to the door on the gallery of a mosque minaret

In order to calculate the coordinates of points, there should be two polygons near the mosque that exist on the ground and their coordinates should be known. The following two methods can be applied; the calculation of coordinate and direct measuring of horizontal distances by using electronic distance-meter (EDM instrument) and the determining of the position by the resection method.

3. The calculation of coordinate and direct measuring of horizontal distances

P1 polygon on the ground and near the mosque, with known coordinates, in a visible line to C, with D being the edge points of the door placed in the direction of the qibla on the gallery of minaret and a P2 polygon is located which can provide a connection to the P1 polygon. Once these points are obtained, a non-reflective electronic distance measuring is set up on the P1 point and a connection is made to the P2 point and the instrument is oriented to the C and D points on the minaret. The βC and βD horizontal angles and the P1C, P1D horizontal distances are measured. To ensure validity of the measurements the process was repeated.

Using the coordinates of $P_1$ and $P_2$ polygons, $(P_1P_2)$ bearing (Figure 3),

$$(P_1P_2) = \arctan\left(\frac{Y_2 - Y_1}{X_2 - X_1}\right) \quad (5)$$

is calculated by which equation (Bannister et al., 1998; Kahmen & Faig, 1998; Ghilani & Wolf, 2012; Kavanagh & Mastin 2014) of the $(P_1C)$ and $(P_1D)$ bearings are obtained.

$$(P_1C) = (P_1P_2) + \beta_C \quad (6)$$

$$(P_1D) = (P_1P_2) + \beta_D \quad (7)$$

In the formula given in (6) and (7),
if $[(P_1P_2) + \beta_C] > 360^0$ and
if $[(P_1P_2) + \beta_D] > 360^0$ then

$$(P_1C) = (P_1P_2) + \beta_C - 360^0 \quad (8)$$

$$(P_1D) = (P_1P_2) + \beta_D - 360^0 \quad (9)$$

are calculated with these equations (Kahmen & Faig, 1998). Considering the $P_1C$ and $P_1D$ horizontal distances, the coordinates of C and D are obtained from following equations (Bannister et al., 1998; Kahmen & Faig 1998; Ghilani & Wolf 2012), Kavanagh & Mastin, 2014).

$$Y_C = Y_1 + P_1C\sin(P_1C),\ X_C = X_1 + P_1C\cos(P_1C) \quad (10)$$

$$Y_D = Y_1 + P_1D\sin(P_1D),\ X_D = X_1 + P_1D\cos(P_1D) \quad (11)$$

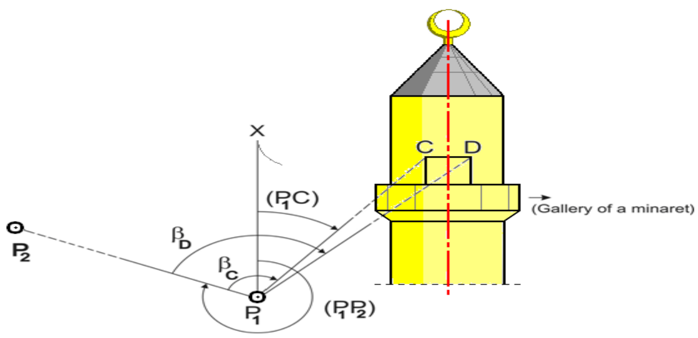



Figure 3. Measuring the P1C, P1D horizontal distances and βC and βD horizontal angles from the P1 point

4. Determining the position by resection method

If it is not possible to measure the horizontal distances of the point on the door on the gallery of minaret, from a polygon, the resection method is applied. The (P1P2) bearing is obtained by equation (5) by benefiting from the coordinates of P1 and P2 polygons. The measured P1P2 length is controlled by the following equation.

$$P_1P_2 = \sqrt{(Y_2 - Y_1)^2 + (X_2 - X_1)^2} \quad (12)$$

In the CP1P2 and DP1P2 triangles; by benefiting from lengths which is calculated by (12) equation and the measured angles, P1C, P1D lengths are obtained Sinus equation, (Bannister et al., 1998; Kahmen & Faig 1998; Ghilani & Wolf 2012; Kavanagh & Mastin 2014).

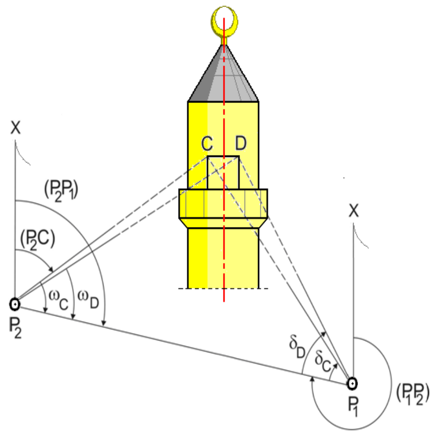



Figure 4. Measuring ωC, ωD, δC, δD angles which belong to points C, D on the minaret from the P1 and P2 polygons

By benefiting from (P1P2) bearing which is obtained by equation (5), (P2P1) bearing (P2P1) = (P1P2) ±180° is obtained by equation. (P1C), (P1D), (P2C) and (P2D) bearings are obtained from the following relationships (Wolf & Brinker 1989).

$$(P_2C) = (P_2P_1) - \omega_C \quad (13)$$
$$(P_2D) = (P_2P_1) - \omega_D \quad (14)$$
$$(P_1C) = (P_1P_2) + \delta_C \quad (15)$$
$$(P_1D) = (P_1P_2) + \delta_D \quad (16)$$

The coordinates of the C and D points are calculated with the following geodesic relationship (or geodesic rule) by using the coordinates of P1 and P2 polygons and considering the calculated lengths and bearings (Kahmen & Faig, 1998; Ghilani & Wolf 2012; Kavanagh & Mastin, 2014).

$$Y_C = Y_1 + P_1C\sin(P_1C),\ X_C = X_1 + P_1C\cos(P_1C) \quad (17)$$
$$Y_D = Y_1 + P_1D\sin(P_1D),\ X_D = X_1 + P_1D\cos(P_1D) \quad (18)$$

Using the P2 polygon and in a similar way the coordinates of C and D points are calculated for control.

5. Calculating the qibla bearing angle by using the coordinates of the door on a minaret

In geodesic measurement and application studies, form of the earth is assumed to be a plane on the fields up to 50 km$^2$ on the face of the earth (Hooijberg, 1997). On this plane the qibla directions [(CK), (DK) bearings] passing through the C and D points which are on the minaret parallel to each other and the CD line is in a vertical position to the qibla direction (Figure 5).

Using the coordinates of the C and D points, the (CD) bearing is calculated given in the 2nd section above.

$$(CD) = \arctan\left(\frac{Y_D - Y_C}{X_D - X_C}\right) \quad (19)$$

$$(DC) = (CD) \pm 180^0 \qquad (20)$$

Beside these, the qibla bearing angles [(CK), (DK)] passing through the C and D points are obtained by the following equation.

$$(CK) = (CD) + 90^0 \qquad (21)$$

$$(DK) = (DC) - 90^0 \qquad (22)$$

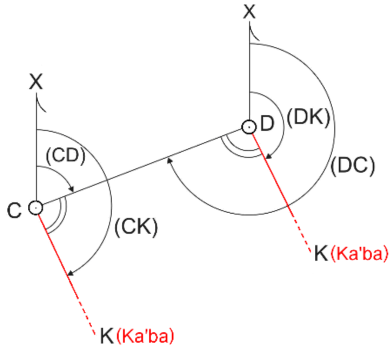



Figure 5. Determination of the qibla bearing angles from C and D points which belong to the door on a minaret

6. Determining the accuracy of qibla direction shown by the door on the minaret

The electronic distance-measuring is set up on one ($P_1$) of the polygons around the mosque and is oriented to the other polygon ($P_2$) to which a connection can be provided. A reflector is attached to a corner of the mosque then the $P_1P_2$ horizontal length and β horizontal angle is measured (Fig. 6). By means of the coordinates of the $P_1$, $P_2$ polygons, the ($P_1P_2$) bearing is obtained by equation (5). From the measured β angle and $P_1P_2$ horizontal distance, the ($P_1P_2$) bearing and the coordinates of the P point are obtained by the following equation (Kahmen & Faig 1998).

$$(P_1P) = (P_1P_2) + \beta \qquad (23)$$

$$Y_P = Y_1 + P_1P\sin(P_1P),\ X_P = X_1 + P_1P\cos(P_1P) \qquad (24)$$

The coordinates of the P point from the country rectangular coordinate system are transformed into geographical coordinates ($\varphi_P$, $\lambda_P$) (Hooijberg, 1997). The calculation of the transformation can be carried out in double or single variable convergent series. The transformation of the UTM rectangular coordinates into geographical coordinates can be easily achieved with NetCad software (Hamdanı et al., 2020).

The qibla azimuth angles are obtained by considering geographical coordinates of a calculated corner of the mosque and geographical coordinates of the Ka'ba in Mecca, Saudi Arabia by equation (1); the meridian convergence (γ) is calculated by the formula in equation (4) and the precise qibla bearing angle is obtained by evaluating the position of the mosque according to the segment medium meridian as shown in Figure 2. The differences between the qibla bearing angle [(CK) = (DK)] shown by the doors of the minarets and precise qibla bearing angle (α) was calculated for each one of the mosques in this study. The differences that were obtained were evaluated according to the average of the absolute errors.

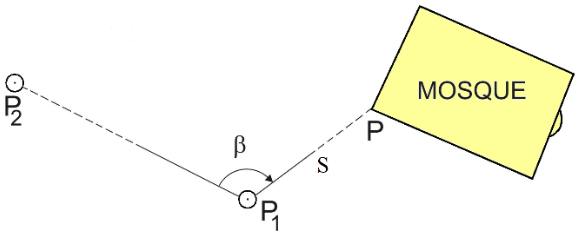



Figure 6. Measuring a corner of the mosque using the $P_1$ and $P_2$ polygons by polar coordinate method.

**Result and Discussion**

For this study three historical mosques (Eski, Üç Şerefeli and Selimiye) in Edirne were chosen (Figure 7). Some of the technical features of these three historic buildings, the names of their architects and who they were built on are briefly given below.

1. Edirne Ancient Mosque

The construction of the famous mosque of Ulu Mosque was started between 1402 and1403 by Emir Süleyman Çelebi (1377-1410). It was completed in 1414 by Sultan Çelebi Mehmet (1389-1421). The architect of the mosque is Hacı Alaaddin of Konya and his assistant is Kalfa Ömer ibn İbrahim. The mosque, which has two minarets, enters the multi-united and multi-domed mosque group. It is the first example of the classical turning-over from the early period when the place of the last congregation formed with columns and vaults for the worship of those who are not praying times (Ilci et al., 2018; Ikbal, 2019).

2. Three gallery of minarets Mosque

It was built between 1437 and1447 on behalf of Sultan II. Murad (1402-1451). The architect of the mosque is Muslihiddin, his assistant is Şahabettin. It is the first example of transition from Seljuk to Ottoman architecture. The mosque patron, the second element added to the mosque architecture tradition in the early period, was first applied to this structure. There are four minarets of different sizes and widths placed on each side of the courtyard. It is the first glass to have a minaret at this altitude which is three honorable at the height of 81 m (Saksono et al., 2018; Ikbal, 2019).

3. Selimiye Mosque

The monumental structure that the architect Sinan built at the age of 80 and which he called master craftsmanship was built between 1569 and 1575 on behalf of Sultan II. Selim (1524-1574). The structure built of cut stone covers an area of 2475 m2 including 1620 m2 of interior. The dome is 43.28 m in altitude, 31.30 m in diameter, bigger than the dome of the Hagia Sophia Cami. There are four minarets around the main dome, three gallery of minarets of which are honored with a diameter of 3.80 m and a height of 70.89 m (Doyle, 2018; Ikbal, 2019).

The minarets in each mosque were numbered from the northwest in clockwise direction. The doors of the minarets were numbered from bottom to top. Firstly, the polygons which are in the country coordinate system, around the mosques were obtained. From the polygons using the polar coordinate method, the horizontal distances of the marked points of the doors located on the minarets and chosen each corners of the historical mosques are measured directly and their coordinates were calculated.

The positions of the edges of doors on the minarets of the Selimiye mosque were determined by the resection position method.  The rectangular coordinates of determined corner of each mosque were transformed into geographical coordinates.

These transformation calculations obtained by means of netcad software which is used in the geodesy engineering of Turkey. The qibla azimuth angles are calculated by the formula in equation (1) formula using the geographical coordinates obtained for each mosque; the geographical coordinates of Ka'ba mosque in Mecca and the qibla bearing angles were obtained as shown in Table 1.

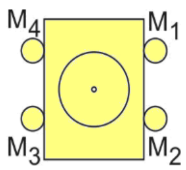
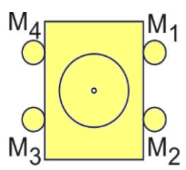
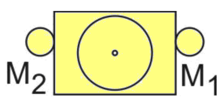

Figure 7. The horizontal position of the Selimiye, Üç şerefeli and Eski mosques and their minarets in Edirne

Table 1. The geographical coordinates of each corner of the 3 historical mosques in Edirne, the qibla azimuth angles and the precise qibla bearing angles

| Mosque Name | Geographical coordinates | | Qibla | Precise qibla bearing |
|---|---|---|---|---|
| | Longitude λ (°) | Latitute φ (°) | Azimut Angle (A) | angle (α=A+γ) |
| Selimiye Mosquee | 26°33’36” | 41°40’45” | 147°17’00” | 147°34’34” |
| Three gallery of minarets M. | 26°33’13” | 41°40’44” | 147°16’10” | 147°33’59” |
| Ancient M. | 26°33’22” | 41°40’39” | 147°16’22” | 147°34’05” |

The qibla bearing angles obtained by the coordinates of the doors were calculated and compared with the precise qibla bearing angles shown in Table 1. The average of the absolute errors for each mosque and each minaret were calculated and the results can be seen in Table 2. The bearing angle which passes through the edge points of the showing the direction of qibla must be calculated by considering their positions, and the qibla bearing angle must be obtained depending on these bearing angle values. The precise bearing angles of the mosques were approximately equal value since they were located close to each other. In the evaluation general accuracy, the precision of qibla bearing angle of the doors of minarets of Selimiye mosque was better than the other two mosques. It has seen that showing pains when in the process of building this mosque has affected on the precision. The qibla precision of the doors on M3 minaret of Üç Şerefeli mosque was better than the other minarets. The accuracy of the qibla directions of the, M2 M4 minarets of the Üç Şerefeli mosque and the M1 minaret of Eski mosque were lower than the other minarets. This error is due to the inaccurate location of the doors.

Table 2. The qibla bearing angles shown by the doors on the minarets of each mosque, the differences between them, the precise value and average of absolute errors

| Mosque Name | Minaret Number | Door Name | Qibla bearing angles | Differences | Average of absolute errors | |
|---|---|---|---|---|---|---|
| | | | | | Minaret | Mosque |
| Selimiye Mosquee | M1 | 1 | 137°29’43” | 10°04’51” | ±8°05’42” | ±7°54’32” |
| | | 2 | 144°44’47” | 3°05’52” | | |
| | | 3 | 158°40’55” | 11°06’22” | | |
| | M2 | 1 | 135°07’45” | 12°26’49” | ±6°43’40” | |
|   | | 2 | 140°14’30” | 7°20’03” | | |
| | | 3 | 147°10’26” | 0°24’08” | | |
| | M3 | 1 | 139°52’48” | 7°41’46” | ±5°24’31” | |
| | | 2 | 142°10’52” | 5°23’42” | | |
| | | 3 | 150°42’38” | 3°08’05” | | |
| | M4 | 1 | 135°24’44” | 12°09’50” | ±11°24’17” | |
| | | 2 | 129°35’17” | 17°59’17” | | |
| | | 3 | 143°30’48” | 4°03’46” | | |
| Three gallery M. | M1 | 1 | 143°38’54” | 3°55’05” | ±3°55’05” | ±9°36’24” |
|   | M2 | 1 | 121°40’59” | 25°53’00” | ±25°53’00” | |
| | M3 | 1 | 146°47’55” | 0°46’04” | ±1°58’27” | |
| | | 2 | 144°30’38” | 3°03’20” | | |
| | | 3 | 149°39’55” | 2°05’56” | | |
| | M4 | 1 | 121°40’59” | 25°53’00” | ±25°21’16” | |
| | | 2 | 122°44’26” | 24°49’32” | | |
| Ancient M. | M1 | 1 | 117° 51’03” | 29°43’02” | ±29°43’02” | ±18°13’17” |
|   | M2 | 1 | 165°40’38” | 18°06’33” | ±12°28’25” | |
| | | 2 | 154°24’22” | 6°50’16” | | |

## Conclusion

Depending on qibla direction shown by the doors of the minarets of three historical mosques located in Edirne, it has been seen that absolute average errors change between 8° and 29° when the precisions are investigated with regard to the definite qıblah directions of the mosques. It has been fixed that among three historical mosques, the qibla direction of the doors of the minarets of Selimiye mosques have more accuracy than the other mosques.

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