

# Novel (RDQ) method for Precise Qibla determination using GNSS Built in a Computer Software

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**Abstract**— Qibla direction is vital for Muslims for their five prayers each day. In addition, Mosques need to be precisely directed towards The Sacred Mosque in Mecca for praying. This research will provide a novel method for Qibla direction determination applicable globally for different users precisely with respect to the true north direction without the need of using expensive Gyrotheodolites or inaccurate compasses. Precise equations have been included in the algorithm of the stand-alone program to orient Qibla direction using GNSS with providing report about error analysis in the obtained direction. The results of practical field test which was conducted to compare the Relative Direction of Qibla (RDQ) method with the traditional method (utilized by the Engineer's Department of Kurdistan's Ministry of Endowment & Religious Affairs) show that there is at least  $\pm 3^\circ$  variation in the assigned direction. The advantage of this method in addition to the precision is availability globally for different users through a dedicated stand-alone software. As a conclusion, the submitted study is strongly recommended to be used because of its high precision and wide range applicability.

**Keywords-component;** GNSS, Geodetic Azimuth, Qibla Direction

## I. INTRODUCTION

Muslims need to head towards The Sacred Mosque in Mecca for their five daily prayers according to the Holy Quran (Qur'an, 02:144). As a result, the mosques need to be precisely oriented towards the Sacred Mosque. According to [1], [4], [5] and [6], During the past centuries, several approaches have been implemented to determine the Qibla direction depending on the astronomical observations from the sun and the circumpolar stars. After the advent of satellite positioning technology such as GPS, which is more precise and weather independent as stated by [3], the Qibla direction determination become easier and more precise. Consequently, new methods

have been used to determine the Qibla direction at any location . Each method has a number of advantages and limitations.

Many researches have been conducted on Qibla direction determination, but the majority are not considering the precision as the main approach. In addition, there is a significant variation in the coordinates of Qa'ba presented by each paper.

According to literature, the main approach of Qibla direction determination that is currently used is based on using a handheld GPS receiver integrated with a digital compass which are also available in many smart phones. However, it is obvious that such method is not precise and has no accuracy analysis information, because the GPS positioning technique of such method is stand-alone which is only accurate to about 3 meters and the digital compass is accurate to several degrees variation depending on the magnetic field of the location of observation. On the other hand the direct method of Qibla orientation determination could be performed using gyro-theodolite which is a very expensive instrument.

The above mentioned methods mainly depend on making observations with the true north or the magnetic north and applying the correction for the deviation between them. However, it is known that accurately orientation to the true north (TN) is a difficult procedure in practice. In addition, the constraints of the true north direction orientation as a reference for azimuth determination which is shown in Fig 1, can be practically avoided only if we can find an alternative reference instead of the true north direction or the non-precisely defined magnetic north direction. Consequently, the appropriate alternative as it is shown in the current research is that based on mathematically definition of the true north.

The RDQ method implemented in this paper uses RTK GNSS technique for precise position determination of two

points and digital theodolite for precise Qibla direction determination from the baseline of the two points. Furthermore, a computer software is developed to perform the necessary mathematical computations to present the required angle of Qibla direction from the baseline of the two points. In addition, an accuracy analysis report is provided for the scenario to analyze the quality of the output result.

The computation of Qibla direction for this paper is based on Vincenty equations for azimuth determination of the geodesic line which is the line that has the shortest distance between the sacred Mosque and the point at which the Qibla direction is determined. In addition, All programming for this study were done in Visual Basic, and for the purposes of computation the WGS84 ellipsoid was chosen.

## II. GEODETIC AZIMUTH DETERMINATION

The geodetic approach used in this research is based on Inverse computations which means that if you are Given any selected two points on the surface of the ellipsoid you can find the geodesic distance between the points, and then the forward azimuth can be determined as the main results of the inverse computations.

The main idea of Relative Direction of Qibla (RDQ) method is to extract the direction of Qibla relatively with respect to a selected reference line (P1-P2) which is precisely mathematically defined (from inverse computations) . Regarding this, the obtained azimuth of the selected line (P1-P2) is oriented with respect to the true north Fig 2.



Figure 1 Qibla direction determination by the azimuth from the true north. Picture adapted from the Google Earth

$AZ_{P1-Q}$  is the azimuth of the line P-Q which is Qibla direction. From Fig 2, the following relations can be recognized:

$$AZ_{P1-Q} = AZ_{P1-P2} + \alpha \quad (1)$$

$$\alpha = AZ_{P1-Q} - AZ_{P1-P2} \quad (2)$$

The angle ( $\alpha$ ) in (1&2) represents the relative direction of the line P1-Qibla.

$AZ_{P1-Q}$  and  $AZ_{P1-P2}$  are the azimuths of the line P1-Qibla and the line P1-P2 respectively.

Now the observer can measure accurately the direction of Qibla by orienting from occupied position (P1) to the visible position (P2) and open in the clockwise direction the angle ( $\alpha$ ).

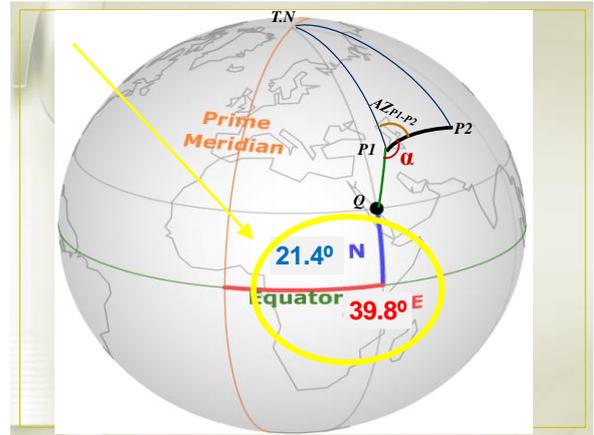


Figure 2 RDQ approach for Qibla assignment. Figure adapted from [2]

For the purpose of this research, the Vincenty method for inverse computations has been used for achieving precise results from the computations. With regard to Vincenty method [7], the inverse computation is performed using the following formulae:

$$\lambda = L \text{ (first approximation)} \quad (3)$$

$$\sin^2 \sigma = (\cos U_2 * \sin \lambda)^2 + (\cos U_1 * \sin U_2 - \sin U_1 * \cos U_2 * \cos \lambda)^2 \quad (4)$$

$$\cos \sigma = \sin U_1 * \sin U_2 + \cos U_1 * \cos U_2 * \cos \lambda \quad (5)$$

$$\tan \sigma = \sin \sigma / \cos \sigma \quad (6)$$

$$\sin \alpha_0 = \cos U_1 * \cos U_2 * \sin \lambda / \sin \sigma \quad (7)$$

$$\cos 2\sigma_m = \cos \sigma - 2 * \sin U_1 * \sin U_2 / \cos^2 \alpha_0 \quad (8)$$

$\lambda$  is obtained by (9 & 10). This procedure needs iteration starting with (4) until the change in  $\lambda$  is not significant.

$$C = f / 16 * \cos^2 \alpha_0 [4 + f (4 - 3 * \cos^2 \alpha_0)] \quad (9)$$

$$L = \lambda - (1 - C) * f * \sin \alpha_0 \{ \sigma + C * \sin \sigma [\cos 2\sigma_m + C * \cos \sigma (-1 + 2 * \cos^2 2\sigma_m)] \} \quad (10)$$

$$S = b * A (\sigma - \Delta\sigma) \quad (11)$$

where  $\Delta\sigma$  comes from (12,13 and 14)

$$A = 1 + u^2 / 16384 * \{ 4096 + u^2 [-768 + u^2 * (320 - 175 * u^2)] \} \quad (12)$$

$$B = u^2 / 1024 * \{ 256 + u^2 [-128 + u^2 (74 - 47 * u^2)] \} \quad (13)$$

$$\Delta\sigma = B * \sin \sigma \{ \cos 2\sigma_m + 1/4 B$$

$$[\cos \sigma(-1 + 2 * \cos^2 2\sigma_m) - 1/6 B * \cos 2\sigma_m$$

$$(-3+4 * \sin^2 \sigma) * (-3 + 4 * \cos^2 2\sigma_m)]\} \quad (14)$$

$$u^2 = \cos^2 \alpha_0 (a^2 - b^2) / a^2 \quad (14a)$$

$$\tan \alpha_1 = \cos U_2 * \sin \lambda /$$

$$(\cos U_1 * \sin U_2 - \sin U_1 * \cos U_2 * \cos \lambda) \quad (15)$$

$$\tan \alpha_2 = \cos U_1 * \sin \lambda /$$

$$(-\sin U_1 * \cos U_2 + \cos U_1 * \sin U_2 * \cos \lambda) \quad (16)$$

where:

a,b are the semi-major and semi-minor axes of the ellipsoid.

f is the flattening.

L is the difference in longitude, positive east.

s is the length of the geodesic.

$\alpha_1$   $\alpha_2$  are azimuths of the geodesic, clockwise from the north;

$\alpha_2$  in the direction P1-P2 produced.

$\alpha_0$  is the azimuth of the geodesic at the equator.

$U_1, U_2$  are the reduced latitudes of P1 and P2 respectively.

$\lambda$  is the difference in longitude.

$\sigma$  is the angular distance P1-P2 on the sphere.

$\sigma_m$  is the angular distance on the sphere from the equator to the midpoint of the line.

The inverse formulae might not give solution for a line between two nearly antipodal points. However this is not significant for this research, because the antipode of Mecca is located in the ocean and it has a special case that do not need to assign any direction. Furthermore, any direction at this point is the direction of Qibla.

### III. THE RDQ METHOD

For the purposes of calculation the geodetic azimuths between the two selected points (P1, P2) with the Qa'ba position and there distances, a special executable software was written by visual basic language according to a model that takes into account all the possible positions on the earth. Therefore, this program will be applicable in any place on our planet.

Fig 3 shows the flow chart of the program that calculate the RDQ and the accuracy analysis of the assigned direction of Qibla. The general structure of this program is represented by two main forms. The first form consist of two steps, the first one represented by all formulae and its iterations that calculate the required geodetic azimuths and distances. The second one includes the computations of the RDQ and the spherical excess correction for the computed direction Fig 4. Consequently, The second form consist of estimation of the error in the assigned Qibla direction Fig 5.

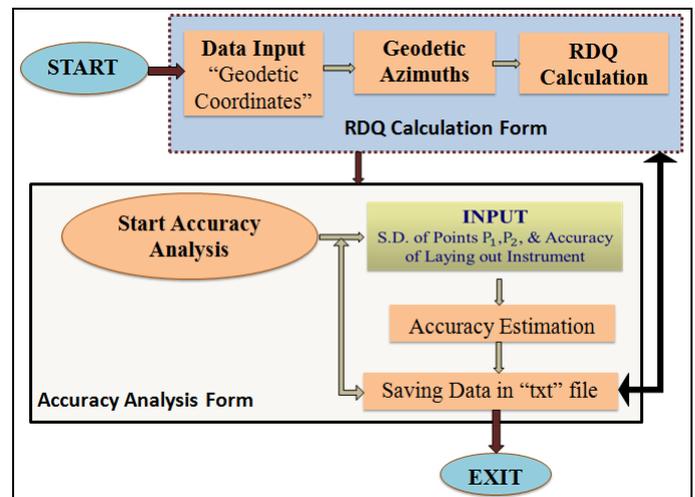


Figure 3 The software flowchart of RDQ computations

As a comparison between the relative direction method and the method of Qibla direction assignment state organization in Kurdistan, an experiment has been conducted at the college of engineering Salahaddin university-Erbil, in order to get the exact difference between the two method. The obtained results show in the most accurate case the difference between them is not less than  $\pm 3^\circ$ . This variation can be understood as  $\pm 1^\circ$  of the digital compass based on handheld GNSS, the rest of the variation come from the precision of the method itself.

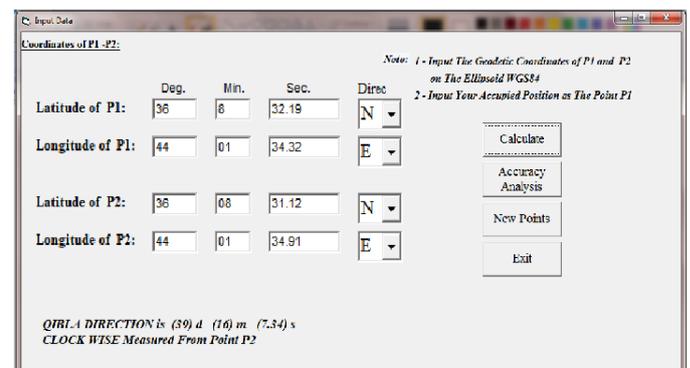


Figure 4 RDQ software for Qibla assignment

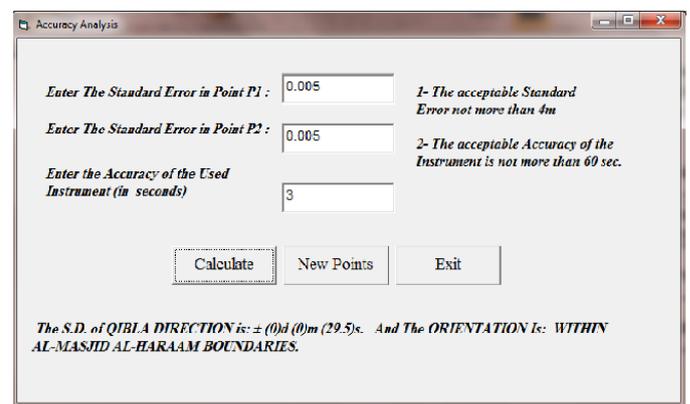


Figure 5 Accuracy Analysis report by the RDQ software

IV. ACCURACY ASSESSMENT

After obtaining the Qibla direction as numerical value (degrees, minutes, and seconds with one decimal after point), the user can also estimate the accuracy in the extracted Qibla direction. Since one can exactly know how much is the assigned direction precisely gives the orientation to the “Qa’aba exactly, or if it is within the Al-Haram boundaries or even within the Mecca city administrative boundaries. Furthermore, the main purpose of the accuracy analysis program, is to give the users an indication about the expected standard error in the assigned Qibla direction regarding the laying out precision, in order to enable the improvement of the obtained results.

The assessment process consists of the estimation of the main factors that are affecting the accuracy of the determined relative direction ( $\alpha$ ). The general formula of the error propagation in the angle ( $\alpha$ ) can be written as follows:

$$\sigma_{\alpha}^2 = \sigma_{ecc}^2 + \sigma_{tar}^2 + \sigma_{inst}^2 \tag{17}$$

where:

$\sigma_{ecc}$  is the error due to eccentricity of centering the instrument at station P1.

$\sigma_{tar}$  is the error due to targeting to the station P2.

$\sigma_{inst}$  is the accuracy of the instrument used in setting out the angle  $\alpha$ .

$\sigma_{\alpha}$  is the obtained total error in the assigned direction, which represents the standard deviation in the RDQ.

The eccentric is illustrated as in Fig. 6 and it can be obtained as in the general formula below:

$$\sigma_{ecc}^2 = (\sin \alpha / D_1)^2 * \sigma_E^2 + (1 / D_2 - \cos \alpha / D_1)^2 * \sigma_N^2 \tag{18}$$

where:

$D_1$  is the distance from station P1 to P2

$D_2$  is the geodetic distance between station P1 and the center of Qa’ba

$\sigma_E, \sigma_N$  are the standard errors of station P1, in easting and northing coordinates respectively.

Since  $1 / D_2$  is enough small to be neglected, (18) becomes:

$$\sigma_{ecc}^2 = (\sin \alpha / D_1)^2 * \sigma_E^2 - (\cos \alpha / D_1)^2 * \sigma_N^2 \tag{19}$$

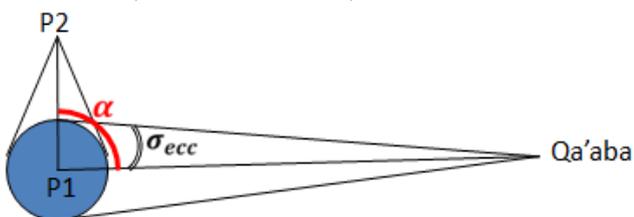


Figure 6 The effect of eccentric error in P1

Since there is no correlation between the error in easting and northing, thus the error in occupied position P1 will be as:

$$\sigma_E = \sigma_N = \sigma_i.$$

Therefore, (19) can be written as:

$$\sigma_{ecc}^2 = (\sigma_i * (\sin \alpha - \cos \alpha) / \sqrt{2} / D_1)^2 \tag{20}$$

The error due to targeting ( $\sigma_{tar}$ ) shown in Fig 7 can be determined as in the formula below:

$$\sigma_{tar} = \sqrt{((\sigma_Q / D_2)^2 + (\sigma_{p2} / D_1)^2)} \tag{21}$$

where:

$\sigma_Q$  &  $\sigma_{p2}$  are the standard error in position of Qibla and P2, respectively.

$D_1$  &  $D_2$  are the distances from P1 to P2 and Qa’ba respectively.

Since the setting out process of the direction ( $\alpha$ ) depends only on the orientation to the point P2 and the calculated value of ( $\alpha$ ), thus the first term in (21) can be neglected and it becomes as:

$$\sigma_{tar} = \sigma_t / D_1 \tag{22}$$

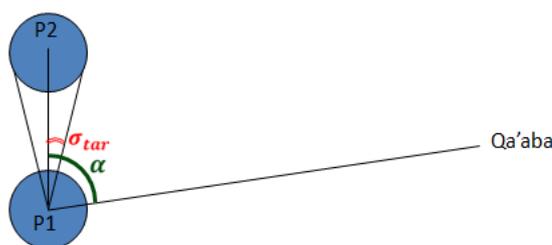


Figure 7 The effect of targeting error towards P2

As an accuracy analysis, three figures, Fig 8,9 and 10 have been presented to illustrate the effect of the position error of the base line points P1 and P2 on one side, and the effect of the eccentric error (RMSE of P1) in comparison with the pointing error (RMSE of P2) on the other side.

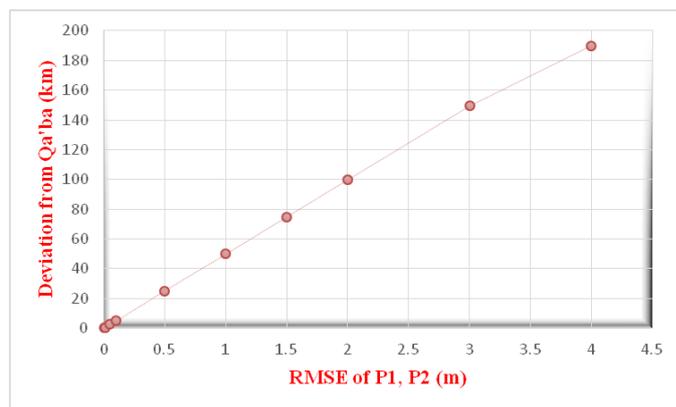


Figure 8 Deviation of assigned direction from the center of Qa’ba caused by  $\sigma_{\alpha}$ , where RMSE of P1 = RMSE of P2

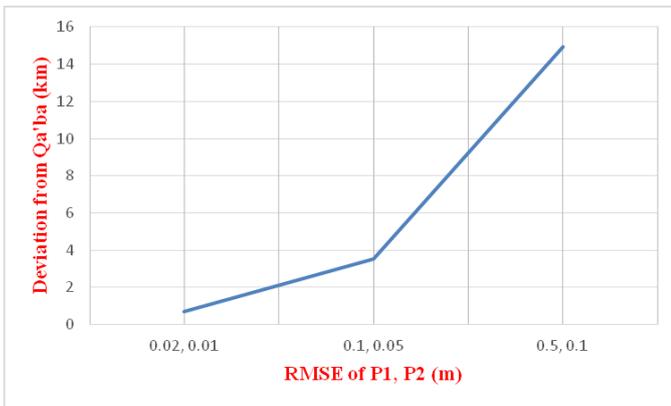


Figure 9 RMSE of P1 > RMSE of P2

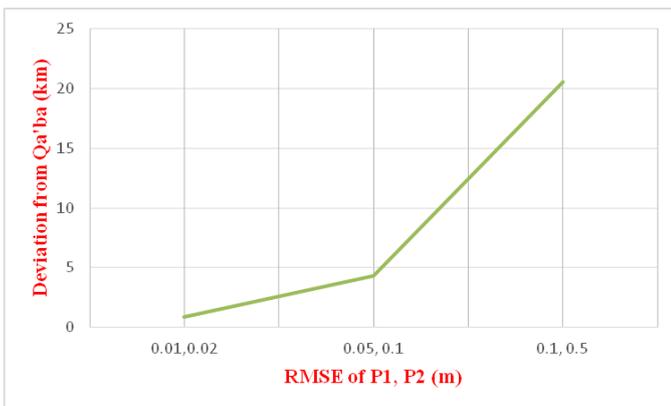


Figure 10 RMSE of P1 < RMSE of P2

## V. CONCLUSIONS

1- Reviewing the published researches about Qibla direction around the world, gives that the RDQ method (current research) can be regarded the novel method that precisely global define the Qibla direction.

2- Using RDQ method gives the ability of skipping the needs of true north detection and at the same time its provide the precisely direction measured from it .

3- During the field tests it was found that the difference between the Qibla direction using the RDQ method and the method of the Engineer's Department of Kurdistan's Ministry of Endowment & Religious Affairs, in best conditions, was within ( $\pm 3^\circ$ ) regardless the precision of the handheld GNSS device which was used in the test. This error causes a deviation from the actual position of Qibla in about ( $\pm 88$  km) which is out of Mecca city boundaries in case of Erbil city as an example.

4- The accuracy of the direction determined by RDQ, mainly based on the accuracy of the position of baseline points (P1 and P2). However, the accuracy of Qibla assignment depends on the accuracy of the position of the points (P1 and P2) and

the precision of the layout of the angle of the relative direction (instrument angular accuracy). Fig. 8,9 and 10 show that the error in position of the points P1 and P2 is directly proportional to the deviation of the relative Qibla direction, despite the precision variation of both points.

6- It is recommended to establish the baseline points P1 & P2 in similar accuracy as much as possible, in order to reduce the error in Qibla assignment and consequently reduce the deviation from Qa'aba.

7. The RDQ method can solve the problem of Qibla assignment in North America mentioned by [1] (as a yet standing problem) and it validates that they have to follow the geodesic direction in Qibla direction.

## ACKNOWLEDGMENT

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