Vol. 9 No. 1 (2022): 89-102

Online Journal Research in Islamic Studies

Received: 2021-10-28 Accepted: 2022-06-29 Published: 2022-06-30

Original Article

Development of Qibla Direction Determinant Using Sun Shadow

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ABSTRACT

The determinant of direction of the Kaaba or Qibla is important to Muslim as it is an obligation for Muslim prayer. A study shows a degree of azimuth displacement will result to a 138.3 km difference, meaning the direction is facing 138.3 km away from Kaaba. Thus, to ensure that the direction is facing the Kaaba, the accuracy of the direction is essential. Therefore, this study aimed to discuss the method of determining the Qibla direction using Sun Shadow, that can determine the times of Sun shadow facing the Qibla direction for various location at various time. The method is published in the form of Microsoft Excel to demonstrate how the formulation is practiced. The method is tested on 5 locations, representing various direction from Mecca, and Equator of the earth, on solar Solstice and Equinox. The method is computed using Jean Meeus Astronomical Algorithm. The result show that the method capable of determining direction of the Qibla at any given location and times with the accuracy error of 30 arc second. The accuracy of the method is better phone compass which has average error of 20 minute. The method will help Muslim in authenticating their Qibla direction by using Sun shadow.

Keywords: Qibla Determination, Qibla Apps, Phone Compass, Rashdul Qibla, Sun Shadow

Introduction

Muslims need the direction of Qibla for performing in performing obligation to Allah. This includes Muslim prayer, slaughter of livestock, commended direction for supplications and alignment for the Muslim grave[1]. The qibla direction can be defined as the azimuthal direction of the shortest distance facing the intersection point between the circle of horizon and the great

[1] Ibnu Rusyd, *Bidayatul Mujtahid*, ed. Besus Hidayat Amin, Mukhlis Mukti, and Ahmad Taufiq Abdurrahman (Jakarta: Pustaka Azzam, 2006).

circle passing in the direction of location zenith and Kaaba in Mecca [2]. The shortest distance means there are only one direction to of Qibla, without the addition of the shorted distance, there would two directions of Qibla, the shortest Distance and the longest distance.

As Qibla direction is a requisite requirement for Muslim prayer, it is important to azimuth direction of the Qibla faced by an individual is as accurate as possible. This is because a degree of deviation in azimuth, will result to 138.3 km displacement away from the Kaaba location, and a ten-degree deviation in azimuth will result to 1382.7 km displacement [3]. The case study of azimuth deviation to displacement is portrayed in Figure 1. Seeing the impact deviation to location displacement, it is essential for Muslim landmark location, such as Mosque, Prayer Room, and graveyard to have accurate Qibla direction[4]. This to reduce the error by the public when replicating the azimuth direction at their own home. High accuracy for replication of azimuth direction by the public in their home is not require[5], but it is advisable for the public to find the azimuth direction as accuracy as possible.

Element	Displacement of the qibla direction from Jakarta city with an azimuth error of:			
	1°	10°	15°	20°
Azimuth	296°1′31.53″	305°1′31.53″	310°1′31.53″	315°1′31.53″
Latitude	22°20′25.20″ N	30°30′12.91″ N	34°56′37.59″ N	39°17′35.46″ N
Longitude	40°5′16.82″ E	42°53′20.32″ E	44°51′40.05″ E	47°12′50.74″ E
Plat-earth model (km)	138.3	1382.7	2074.1	2765.4
Spherical model of the Earth (km)	105.3	1053.2	1579.1	2104.3
Ellipsoidal model of the Earth (km)	105.2	1051.6	1577.3	2102.6

Figure 1: Deviation to Displacement Ratio of Azimuth Qibla Direction[6]

Evolution of Method in Finding the Qibla Direction Throughout the Islamic Civilization

During the first centuries after the induction of Islamic religion by the Prophet, the mosque was built without any scientific direction to find the Qibla. Some of the Prophet companion determined that Qibla direction based on the south of their location, based on the direction of Qibla during Prophet time at Madinah. Some companions determine their direction of the Qibla based on the direction of the road leaving the Mecca [7]. The knowledge of folk astronomy also adopted in the effort of finding the Qibla direction. Rising of the Canopus is used by Andalusian to determine their Qibla direction [8]. Similarly, the rising of the Sun during equinoxes, Sunrise during winter and the direction of the north winds is used respectively by Medieval North African, Egyptian, and Yemeni, to determine the direction of the qibla. This evidenced by the position of

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[2] Tono Saksono, Mohamad Ali Fulazzaky, and Zamah Sari, "Geodetic Analysis of Disputed Accurate Qibla Direction," *Journal of Applied Geodesy* 10, no. 3 (2018): 40–69, https://doi.org/10.1515/jag-2017-0036.

[3] Saksono, Fulazzaky, and Sari, "Geodetic Analysis of Disputed Accurate Qibla Direction.", 15

[4] Jayusman, "Akurasi Metode Penentuan Arah Kiblat: Kajian Fiqh Al-Ikhtilaf Dan Sains," *Asas* 3, no. 1 (2014): 1–3.

[5] Ahmad Izzuddin, "Metode Penentuan Arah Kiblat Dan Akurasinya," *(Annual International Conference on Islamic Studies)AISIS XII*, 2010.

[6] Saksono, Fulazzaky, and Sari, "Geodetic Analysis of Disputed Accurate Qibla Direction."

[7] Gerald S Hawkins and David A King, "On the Orientation of the KA'BA," *Journal for the History of Astronomy* 13, no. 2 (1982): 102–9.

[8] Eric Mercier, "Mathematical Geography in the Western Islamic World: Geographical Coordinates of Localities in the al-Maghreb and al-Andalus Localities (9th-18th Centuries)," *Suhayl. International Journal for the History of the Exact and Natural Sciences in Islamic Civilisation* 8, no. 2 (2020): 25–49.

the early Mosque in Andalus, Egypt and Iraq, which follows their folk astronomy and missed the actual direction of the by maximum of 45 degree [9].

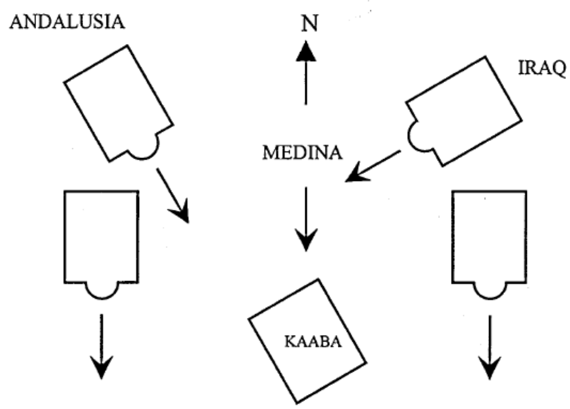

Figure 1: Direction of the Early Mosques

Staring from the 8th centuries, the Islamic Scholar began the translation work of the scientific works by the Persians, Greeks, and Indians. The works, initially for prayer time calculation and time keeping, is then applied to determine the direction of Macca from various geographical coordinate. Ptolemy 'world map from Geography, combine with Greek and Indian trigonometry solution enable the Muslim scholar to develop a mathematical method to calculate the direction of Qibla with approximate accuracy. This leads to the publication of astronomical handbook, that contain a chapter to determine the direction of Qibla, such as astronomical handbook by Ibnu Haitham, Ibnu Sarraj, and al-Khalili. Initially, the mathematical method is simply expressed as,

$$\tan q = \frac{\sin c}{\sin(a - b)} \tag{1}$$

Where q is the Qibla direction, c is the longitude difference between Mecca and calculated location, while a and b are the latitude of the calculated location and Mecca latitude. This mathematical method does not consider the curvature of the earth, approximating the earth is laid out as a flat surface. This approximation result to the mathematical method to contain few degrees of error. . Over the years, the mathematical method began to consider the curvature nature of the earth and adapt the spherical trigonometry for more accurate calculation. King

[9] David A King, "The Orientation of Medieval Islamic Religious Architecture and Cities," *Journal for the History of Astronomy* 26, no. 3 (1995): 253–74.

[10] David A King, "The Sacred Direction in Islam A Study of the Interaction of Religion and Science in the Middle Ages," *Interdisciplinary Science Reviews* 10, no. 4 (1985): 315–28.

[11] King, "The Orientation of Medieval Islamic Religious Architecture and Cities." 67

[12] W S Mada Sanjaya et al., "Determining Qibla Direction Using Al-Biruni's First Method from Kitab Tahdid Nihayat al-Amakin with The Implementation Based on Board Arduino MCU, GPS Module, and Digital Compass," in *2019 International Seminar on Application for Technology of Information and Communication (ISemantic)* (IEEE, 2019), 513–18.

[13] David A King, "The Sacred Geography of Islam," in *Mathematics and the Divine: A Historical Study* (UK: Elsevier, 2005), 161–78.

[14] King, "The Orientation of Medieval Islamic Religious Architecture and Cities." 68

highlighted that a solid trigonometry solution from an anonymous Baghdad astronomer in the 9th century . King cements that most of the trigonometry solution by the following Muslim Scholar are derived from this solution, as their mathematical solution are equivalent to its. The solution is expressed as,

$$\tan q = \frac{\cos c \sin b - \cos b \tan a}{\sin c} \quad (2)$$

The issue of Mathematical solution and astronomical handbooks is it is not well understood and applicable for public usage. The mathematical solution is only accessible for Muslim Astronomer and Mathematician to understood. Thus, 9th century saw an introduction of instrumental solution to help navigate Qibla direction calculation, such as handbooks with compass and astrolabe. Such example is Natulus astrolabe, which contain plates of various latitude to help finding direction of Qibla and al-Kirmani astrolabe, which contain designated Qibla values for given latitude and longitude . The instrumental solution is however, sacrificing accuracy as it is difficult to maintain precision for pre-calculated Qibla values.

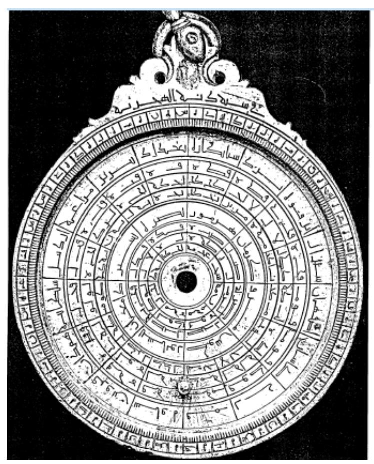

Figure 3: Al-Kirmani Astrolabe with Pre-Calculated Qibla Value

In alternative to Astrolabe, Map that contain Qibla direction is also published to help finding Qibla direction. Map is more elegance alternative for instrumental solution in finding Qibla direction, as Map are easier for travel and usually published along astronomical handbook. One example is map that found on the treatise named Siraj al Dunya wa'l Din dated around 12th century[19]. This map is probably designed for Egypt and Iran localities as the pre-computed Qibla values is most

[15] David A King, "The Earliest Islamic Mathematical Methods and Tables for Finding the Direction of Mecca," *Zeitschrift Für Geschichte Der Arabisch-Islamischen Wissenschaften* 3 (1986): 82–149.
[16] David A King, "A Newly-Rediscovered Abbasid Astrolabe from Baghdad, ca. 900," *Suhayl* 11, no. 1 (2020): 103–16.
[17] David A King, "An Astrolabe from 14th-Century Christian Spain with Inscriptions in Latin, Hebrew and Arabic. A Unique Testimonial to an Intercultural Encounter," *Suhayl. International Journal for the History of the Exact and Natural Sciences in Islamic Civilisation* 5, no. 1 (2003): 9–156.
[18] David A King, *World Maps for Finding the Direction and Distance of Mecca: Examples of Innovation and Tradition in Islamic Science*, vol. 36 (Brill, 1999). .
[19] David A King, "The Culmination of Islamic Sacred Geography," in *Geography and Religious Knowledge in the Medieval World* (De Gruyter, 2021), 179–88.

accurate for Egypt and Iran. Another example is an orthogonal grid dated 14th century by Egyptian Scholar, Ibn Fadlallah al-Umari[20], and non-grid map, with coordinate scale in 16th century. Map for finding Qibla direction a well popular with the public, making its publication can be found as far as 18th century before the introduction of more modern methodology.

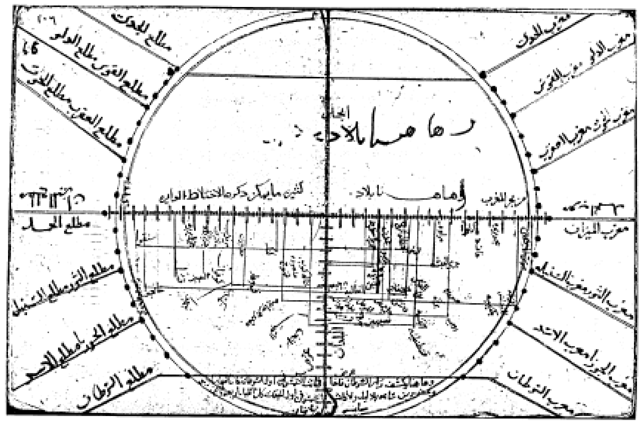

Figure 2: Ancient Qibla Map

Present Method to Determine the Qibla Direction

The determination of azimuth Qibla nowadays is more accessible and accurate. The azimuth can be calculated using trigonometry formulation, with spherical and ellipsoidal correction can be computed to increase its accuracy, which can be calculated using calculator or programming library. Once the azimuth is calculated, the direction can be determined using Ushikata, a stable magnetic compass. There is also Theodolite, where the direction is determined by the Sun position, further increasing the accuracy of Qibla azimuth direction. Another method to accurately determine the azimuth Qibla is by using Solar transit observation, where Sun will be directly above Kaaba, and its shadow will point at the direction of Qibla[22]. Probably the most accessible method to determine the Qibla azimuth is by using phone magnetic compass [23]. This indicate that determining the azimuth Qibla is now more effortless than before.

However, the effortless alternative in determining the Direction of the Qibla does not necessarily translate to more accurate azimuth determination. Determining Qibla direction using mobile phone, is found to prone to error up to 20-degree deviation, depending on phone and application type [24]. This is due to disruption to other magnetic object such as laptop and medical device, in

[20] King.

[21] King, *World Maps for Finding the Direction and Distance of Mecca: Examples of Innovation and Tradition in Islamic Science, 142*.

[22] Nurulhuda Ahmad Zaki et al., “Cerapan Istiwa’ Matahari Dalam Penentuan Arah Kiblat Di Malaysia,” *Sains Humanika* 8, no. 3 (2019): 41–60.

[23] Nurulhuda Ahmad Zaki, Raihana Abdul Wahab, and Mohammaddin Abdul Niri, “Kesan Revolusi IR 4.0 Terhadap Perkembangan Dan Ketepatan Aplikasi Kiblat Dalam Telefon Pintar,” *Jurnal Fiqh* 21, no. 2 (2020): 67–95.

[24] Nurulhuda Ahmad Zaki and Muhammad Asyraff Anuar, “Analisis Perbandingan Aplikasi Penentuan Arah Kiblat Dalam Telefon Pintar Asus Zenfone 2 Dan Huawei P9 Lite,” *Voice of Academia (VOA)* 13, no. 2 (2018): 35–47.

the vicinity of the mobile phone during the determination of Qibla direction [25]. As using phone magnetic compass is prone to error, there need to be alternative to determine the Qibla direction using mobile phone.

Another alternative is by using Sun Shadow, as the position of the Sun can be calculated accurately, it computed azimuth can be used to determine the direction of the Qibla. The most popular application of Sun shadow for qibla direction determination is Istiwa' Azam. This phenomenon occurs when the Sun is directly above the Kaaba and its shadow will point out to direction of the Qibla. However, this method is only available twice a year, making it not applicable for daily usage[26]. Another method is by estimating the time of the azimuth Sun facing the Qibla. This method is extensively studied in Indonesia[27], however most of the method application are limited for Indonesia coordinate computation and does not include worldwide application. In Malaysia, this method published by Malaysia Surveyor Department and Universiti Sultan Zainal Abidin as e-QLIM Falak Suite and Kalkulator Falak respectively[28], however its applicability outside Malaysia is not studied and tested. Accurate Time, software developed by Mohammad Odeh, has the feature to estimate the time of the azimuth Sun facing the Qibla, however the details of the formula and computation is not discussed [29], limiting the potential for future research and development. Reviewing the current gap of research on determination of Qibla Azimuth using Sun shadow, this research endeavor to discuss the method to time of the Sun azimuth facing the Qibla, including its computation formulae, its accuracy, and its applicability worldwide. The research aimed to produce an excel software to demonstrate how its applicability.

Methodology

The methodology will involve three parts, computation formulae, implementation development, accuracy test design. Computation formulae will describe the formula involve in estimating the time of the Sun azimuth facing the kiblah. Implementation development is a summary on the development of the method implementation on excel file. Accuracy test design is the design that is used to test the calculation.

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[25] Ahmad Zaki and Anuar, " Analisis Arah Kiblat", 40.

[26] Ahmad Zaki et al., "Cerapan Istiwa' Matahari Dalam Penentuan Arah Kiblat Di Malaysia. 45"

[27] Muhammad Nu'man Alkarim, "Perancangan Aplikasi Perhitungan Rashdul Kiblat Harian Dengan Java 2 Micro Edition (J2ME) Pada Mobile Phone" (UIN Walisongo, 2015); Slamet Hambali, "Ilmu Falak Arah Kiblat Setiap Saat," *Yogyakarta: Pustaka Ilmu Yogyakarta*, 2013; M Ruston Nawawi, "Studi Komparasi Metode Hisab Rashdul Kiblat Dua Kali Dalam Sehari Dalam Kitab Tsimarul Murid Dengan Kitab Jami'Al-Adillah Ila Ma'rifah Simt Al-Qiblah" (UIN Walisongo, 2019); Moedji Raharto and Dede Jaenal Arifin, "Telaah Penentuan Arah Kiblat Dengan Perhitungan Trigonometri Bola Dan Bayang-Bayang Gnomon Oleh Matahari," *Jurnal Fisika Himpunan Fisika Indonesia*, 2011; Sakirman Sakirman, "Formulasi Baru Arah Kiblat: Memahami Konsep Rasydul Kiblat Harian Indonesia," *Al-Qisthu: Jurnal Kajian Ilmu-Ilmu Hukum* 16, no. 1 (2018): 1–8; Muhammad Faishol Amin, "Global Rasdhul Qibla: The Probability of Four Times in A Year Study," *JURNAL PENELITIAN*, 2018, 175–88; Muhammad Ikbal, "The Implementation of Qibla Direction According to KH. Ahmad Rifa'i and Its Community Responses at Batang" (UIN Walisongo, 2019); A Jusran Kasim, "Tingkat Akurasi Aplikasi Azimuth Matahari Pada Google Play Store (Analisis Perbandingan Rasd al-Qiblah Harian Sistem Hisab Data Ephemeris Dan Software Hisab Komputer)," *ELFALAKY* 4, no. 2 (2020): 102–19.

[28] Azhari Mohamed, Persatuan Falak Syar`i Malaysia, and Wan Kamel Wan Hussain, *Falak Suite* (Universiti Malaya, 2007), http://malcat.uum.edu.my/kip/Record/um.u756795/Description; Ahmad Taufan Abdul Rashid, "Kalkulator Posisi Hilal Ver. 2.2009," Projek Aplikasi Falak A.T, 2009, https://www.appfalak.com/index2.php?name=hilal.

[29] Mohammad Odeh, "Accurate Times 5.6.1," International Astronomical Centre, 2019, http://www.astronomycenter.net/accut.html?l=en.

Computation Formulae

As the Qibla determinant is calculated using Sun Shadow, a reliable ephemeris is needed to ensure accurate solar position. Jean Meeus Astronomical Algorithm is used in this research, as it is requiring less programming line and capable of producing precise computation with 10" of error[30]. The formula to calculate the direction of the Qibla from various location is extracted from Saksono et. al[31]. while estimating the time Sun azimuth Qibla is extracted from Hambali[32]. The formulae require minor adjustment to ensure its applicability to worldwide Qibla direction computation. The calculation formulae are as follows

The main body of the paper, 11 pt Calibri (Body), can include titles and subtitles followed by discussion to address: literature review, research question, research design and methodology, result, discussion, study limitations and conclusion. Body text is set in „Text" style (Justified). Paragraphs are separated by a separate line. Please use footnote[33].

Include figures and tables within the body of your paper. DO NOT design your figures using Microsoft word in bits and pieces. This will cause the figure to be distorted during formatting and production. You have to use a drawing tool and import the figure to word.

Calculation Equation of Time, E

$$E = L_0 - 0.0057183 - a + \Delta\psi \cos\varepsilon \tag{3}$$

$$L_0 = 280.4664567 + 360007.6982779\tau + 0.03032028\tau^2 + \tau^3/49931 - \tau^4/15300 - \tau^5/2000000 \tag{4}$$

$$\tau = (JDE - 2451545)/365250 \tag{5}$$

Calculation of Qibla Direction, αA,

$$tan\ \alpha A = \frac{-\ sin\ \Delta\lambda}{sin\ \varphi\ cos\ \Delta\lambda -\ cos\ \varphi tan\ \varphi K} \tag{6}$$

[30] Jean Meeus, *Astronomical Algorithms* (Virginia: Willmann-Bell, 1991), 591.
[31] Saksono, Fulazzaky, and Sari, "Geodetic Analysis of Disputed Accurate Qibla Direction', 22.
[32] Hambali, "Ilmu Falak Arah Kiblat Setiap Saat."
[33] Follow the Chicago Manual of Style for footnote and bibliography.

Where,

K is the Kaaba, A is location on the Earth's surface from where the qibla direction is being sought, O is centre of the Earth (sphere), ϕK is latitude of Kaaba, ϕA is latitude of A, ϕK is co-latitude of the Kaaba (90°−ϕK), ϕA is co-latitude of A (90°−ϕA), Δλ is longitude difference between Kaaba and A (λK – λA), and αA is qibla direction (azimuth of AK at point A).

Calculation of Sun Shadow facing the Qibla

$$\cos(t-U) = tan\delta \frac{cosU}{tan\emptyset}$$

$$If\ U > 0, t = -abs(t-U) + U, else, t = abs(t-U) + U$$
$$WH = 12 + t$$

(7)

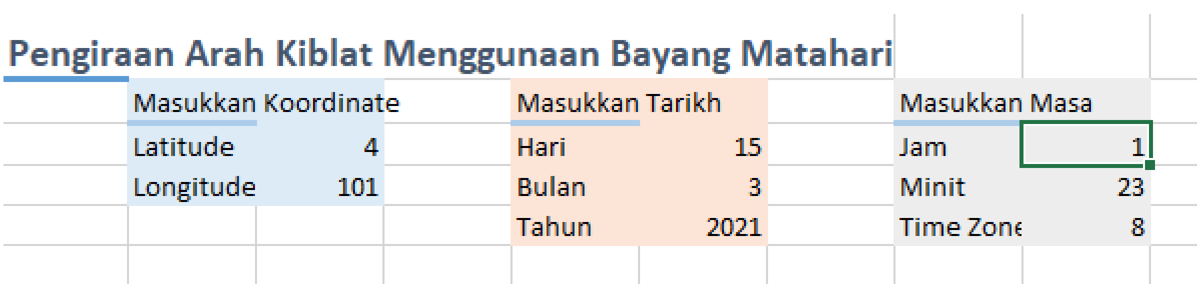
Time of Solar Shadow facing Qibla

$$if\ Time\ Zone > 0,$$
$$Time = WH - e + \frac{Time\ Zone\ X\ 15 - Longitude}{15}\ else,$$
$$Time = WH - e - \frac{abs(Time\ Zone)\ X\ 15 - abs(Longitude)}{15}$$

(8)

Implementation Development

The calculation result is generated using Microsoft Excel to demonstrate the method. This to enable the user to test the method on site to examine its accuracy in determining the Sun azimuth facing the Qibla. The demonstration product requires input of geographical coordinate, date, time zone and local time. The product output is the time of the instant of Sun azimuth facing the Qibla and the bearing of azimuthal difference of Qibla direction and Sun Azimuth. The interface of the demonstration product is portrayed in Figure 5, Figure 6, and Figure 7.


Pengiraan Arah Kiblat Menggunaan Bayang Matahari

Masukkan Koordinate		Masukkan Tarikh		Masukkan Masa	
Latitude	4	Hari	15	Jam	1
Longitude	101	Bulan	3	Minit	23
		Tahun	2021	Time Zone	8

Figure 3: User Input of Coordinate, Date and Time

Waktu Bayang Matahari Menghadap Kiblat		
12	14	21.42959

Figure 4: The Result of Time Sun Shadow facing the Qibla

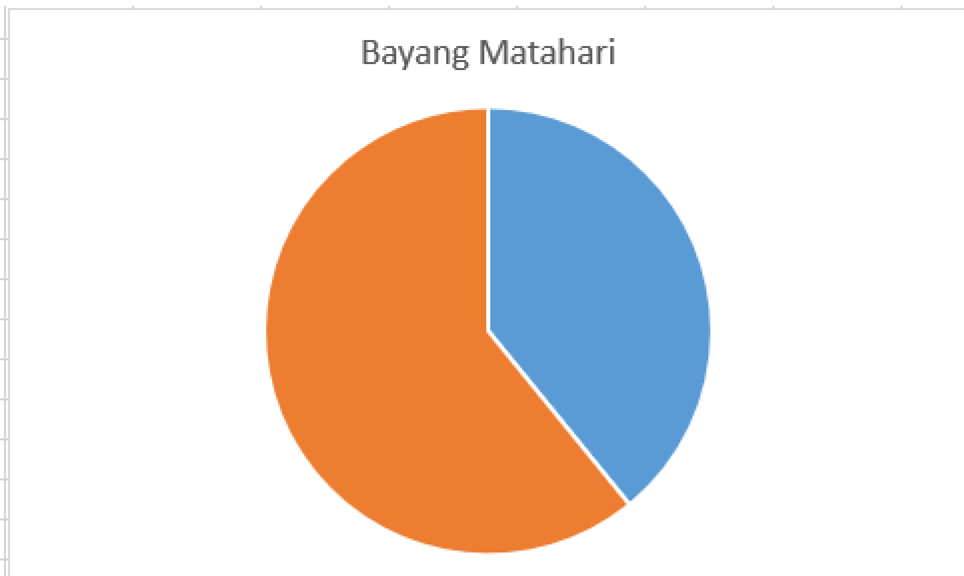


Figure 5: Pie Chart of Sun Azimuth at the Instant and Qibla Direction.

Calculation Accuracy test

The calculated result is expected to be applicable for any location in the World. Thus, the accuracy assessment is calculation on five locations, representing Block A, Block B, Block C and Block D and Block Equator. The selection of the block is ensured that the software is capable of calculating the direction of the Sun facing the Qibla at any given geographical coordinate. The classification of the Block is portrayed in the figure below. The location for each is listed in the Table 1 and Figure 8. Each location is selected based on Muslim population density on a particular location. Each test is computed on during the extreme position of the Sun, which is Summer-Winter Solstice and Autumn-Spring Equinox, where Sun is located at 23.5° degree of Declination North, 23.5° degree of Declination South, and 0° degree of Declination above the equator.

Figure 6 : Blocks of Location away from Mecca based on Geographical Coordinate

Table 1 : Location Coordinate for Each Block

BLOCK	LOCATION	COORDINATE	TIME ZONE
A	Ontario, Canada	49°15’ N, 84° 30’ W	-5
B	Dagestan, Russia	43°06’ N, 46° 53’ E	+3
C	Buenos Aires, Argentina	34°36’ S, 58° 22’ W	-3
D	Christchurch, New Zealand	43°31’ S, 172° 37’ E	+12
EQUATOR	Pontianak, Indonesia	0°01’ S, 109° 20’ E	+7

Result & Discussion

The computation formulae are tested on one location during 4 extreme solar position, solstice, and equinox. The result of the calculation is as shown in Table 2.

Table 2: Result of Computation

LOCATION	TESTING DATE	QIBLA AZIMUTH	CALCULATED SUN AZIMUTH FACING THE QIBLA	DIFFERENT IN AZIMUTH
ONTARIO, CANADA	Summer Solstice 21 June 2021	50°23'35.68''	50°23'33.39''	0°0'2.28''
	Winter Solstice 21 December 2021		50°23'30.97''	0°0'4.7''
	Autumn Equinox 23 September 2021		50°23'31.9''	0°0'3.77''
	Spring Equinox 20 March 2021		Sun Azimuth not passing the Qibla Direction on this date	
DAGESTAN, RUSSIA	Summer Solstice 21 June 2021	197°24'33.94''	197°24'32.63''	0°0'1.31''
	Winter Solstice 21 December 2021		197°24'26.85''	0°0'7.08''
	Autumn Equinox 23 September 2021		197°24'29.38''	0°0'4.55''
	Spring Equinox 20 March 2021		Sun Azimuth not passing the Qibla Direction on this date	
BUENOS AIRES, ARGENTINA	Summer Solstice 21 June 2021	76°15'41.05''	76°15'38.29''	0°0'2.76''
	Winter Solstice 21 December 2021		76°15'40.29''	0°0'0.76''
	Autumn Equinox 23 September 2021		76°15'41.44''	0°0'0.39''
	Spring Equinox 20 March 2021		Sun Azimuth not passing the Qibla Direction on this date	
CHRISTCHURCH, NEW ZEALAND	Summer Solstice 21 June 2021	255°58'57.19''	255°58'58.62''	0°0'1.43''
	Winter Solstice 21 December 2021		255°59'0.73''	0°0'3.54''
	Autumn Equinox 23 September 2021		255°59'0.38''	0°0'3.19''
	Spring Equinox 20 March 2021		255°59'1.62''	0°0'4.42''
PONTIANAK, INDONESIA	Summer Solstice 21 June 2021	292°43'54.61''	Sun Azimuth not passing the Qibla Direction on this date	
	Winter Solstice 21 December 2021		Sun Azimuth not passing the Qibla Direction on this date	
	Autumn Equinox 23 September 2021		292°40'56.03''	0°2'58.58''
	Spring Equinox 20 March 2021		292°41'9.69''	0°2'44.91''

The method able to predict the time of Sun azimuth facing the qibla direction with average 30 arc second error rate and maximum error of 2 arc minute. The error rate could be attributed to the chosen ephemeris of Jean Meeus. Jean Meeus uses outdated VSOP87 planetary theory [34] and IAU 1980 theory of nutation [35], which attributed to the error rate of 1 arc second. A more modern

[34] P. Bretagnon and G. Francou, "Planetary Theories in Rectangular and Spherical Variables. VSOP87 Solutions," *Astronomy & Astrophysics* 202 (1988): 309–15.
[35] P. K. Seidelmann, "1980 IAU Theory of Nutation - The Final Report of the IAU Working Group on Nutation," *Celestial Mechanics* 27 (1982): 79–106.

ephemeris calculator such as Skyfield and Astropy can increase the accuracy of the method [36]. The method also demonstrated a capability to estimate the time of Sun azimuth facing the qibla direction at any given location and any given date. However, there are times where the method unable to output the desired result. This is due to the declination of the Sun located in a position that is impossible to pass the Qibla direction. This method however is dependent on the availability of the Sun shadow.

Conclusion

A method to determine the direction of the Qibla using Sun shadow is introduced. This method capable of calculating the azimuth of the Sun facing the Qibla at any given location and date with average error rate of 30 arc second and maximum of 2 arc minute. A demonstration Excel Software is developed to help understand and test the method.

Acknowledgement

Special thanks to student of Kolej Pengajian Tinggi Al-Insaniah Johor Bahru for testing the calculation during Istiwa' Azham 2021. Thanks to Geran Penyelidikan Bantuan Kecil Penyelidikan (BK006-2017) from Universiti of Malaya.

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