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A CELESTIAL NAVIGATION APPROACH TO SALAH TIMEKEEPING FOR SEAFARERS

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Abstract: Ensuring religious practices on board ships is essential for the wellbeing of practicing seafarers. Around 18% of seafarers on board merchant ships are Muslim, and practicing seafarers perform Salah – five prayers a day. The prayers must be performed at appointed times during the day, times which depend on the movement of the sun; this is why astronomy is essential for the Islamic world. Presently, astronomical calculations are used to find the right prayer times, and prayer times across the world are available on the Internet, in tables, for major cities on all continents. Since prayer times depend on location, the objective of this paper is to provide seafarers with Salah times with the help of nautical astronomy calculus. This paper presents a method that allows the use of two successive sights taken at two different stars as if they were two simultaneous sights, by reducing the first observation to the zenith of the second observation or vice versa. At least two astronomical lines of position are required to obtain an astronomical fix, meaning two simultaneous sights at two different celestial bodies; however, only the officer on watch is usually on deck and cannot take two simultaneous sights, and the moving vessel changes its dead reckoning position between the two observations. Science and religion are not in antagonistic positions; they may coexist by jointly addressing aspects of human life. The present study may serve as guidance for Muslim seafarers during their voyages in fulfilling their religious obligations.
Key words: Astronomical fix; Celestial navigation; Muslim seafarers; Nautical astronomy; Prayer times (Salah); Same altitude method.

1. INTRODUCTION

Seafaring is a profession characterised by cultural diversity, and performance on board is affected by a friendly environment for the religious practices of seafarers. Around 18% of the seafarers on board merchant ships are Muslim [12], with practicing seafarers finding support in prayer and other practices associated with their faith.

Among the obligations that a Muslim must follow is Salah [1]. This means that the believer is expected to pray five times a day, at appointed times. These five times depend on the movement of the sun, which is why astronomy plays an essential role in Islam.

The five daily mandatory prayers are: *Fajr* (early morning prayer) – between the appearance of dawn and sunrise; *Dhuhr* (midday prayer) – beginning after the sun has passed the meridian and ending just before the start of *Asr*; *Asr* (afternoon prayer) – from the late afternoon until the yellowing of the sun; *Maghrib* (evening prayer) – lasting as long as twilight; and *Isha* (night prayer) – between sunset and midnight.

Presently, the right prayer times are found through astronomical calculations.

Across the world, prayer times are available on the Internet, provided in tables for major cities on all continents. Since prayer times depend on location, this paper aims to provide seafarers with the right Salah times during sea voyages by using nautical astronomy calculus.

The goal of this paper is to present a method that allows the use of two successive sights taken at two different stars as if they were two simultaneous sights. This can be done by reducing the first observation to the zenith of the second observation, or vice versa.

At least two astronomical lines of position are required to obtain an astronomical fix, meaning two simultaneous sights at two different celestial bodies. Usually only the officer on watch is on deck, and cannot take two simultaneous sights at two different stars. Moreover, since the ship is moving on the surface of the Earth, the second sight is made from another dead reckoning position; as is known, a fix by two simultaneous observations requires the same DR position for both observations.

2. RESEARCH METHODOLOGY

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2.1 *Horizon and zenith, altitude and zenith distance*

One of the main lines of the celestial sphere is the zenith-nadir line. This line connects the centre of the Earth's sphere with the point where the observer is located. The extension of this line above the observer's head intersects the celestial sphere at the point called zenith. The diametrically opposed point of the zenith is called nadir.

When an altitude is measured at a star, its image is brought with the help of the sextant onto the plane of the observer's horizon. For simplicity, we use the term *observer's horizon* to represent the plane perpendicular to the zenith-nadir line that passes through the observer's eye. The circle that connects the zenith with the nadir and passes through the observed star is called the *vertical circle* of the star; it is perpendicular to the plane of the observer's horizon. The arc of a vertical circle measured from the horizon to the centre of the star is called *altitude*; the arc measured from the zenith to the centre of the star is called the *zenith distance*.

As the vessel moves on the Earth's surface, its position changes over time, and the position of the zenith on the celestial sphere changes accordingly. This determines a variation in the position of the plane of the observer's horizon with respect to the terrestrial sphere, and hence a variation in the value of the star's altitude and zenith distance.

As a result, the altitude measured at a star – considered immobile on the celestial sphere – will increase due to the movement of the ship if the star is sighted forward of the vessel, and will decrease if the star is sighted astern (Figure 1).

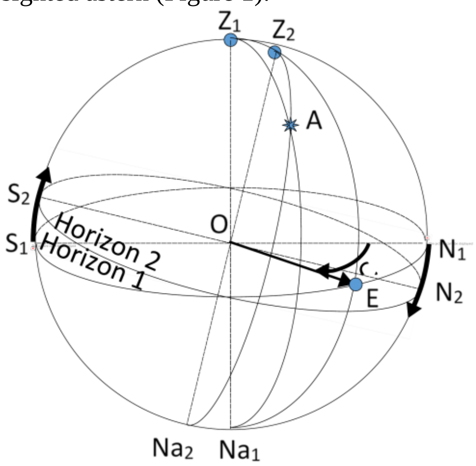

Figure 1 Variation of altitude and zenith distance due to the ship's movement

We note from here that the altitude and zenith distance of a star are constantly changing as a result of the movement of the ship on the Earth's surface.

2.2 *Variation of zenith distance due to the ship's movement*

Suppose that at chronometer time CT_1, in dead reckoning position DR_1, star A is sighted at altitude H_1. The zenith point Z_1 corresponds to the observer's (vessel's) position at that moment. The star's position is considered fixed, unaffected by diurnal motion.

After a time interval (ΔT), in dead reckoning position DR_2, the same star is sighted at altitude H_2. The chronometer time for this moment is CT_2.

As can be seen below (Figure 2), the arc Z_1Z_2 represents the projection on the celestial sphere of the distance (D) travelled by the vessel in the time interval between the two observations. The value of the arc, expressed in arc minutes, is therefore equal to the value of the distance D in nautical miles:

$$\widehat{Z1Z2} = D \tag{1}$$

The zenith distances (z) corresponding to the two observations are Z1A and Z2A, since the star is assumed to have no diurnal motion (Figure 2):

$$z1 = \widehat{Z1A} = 90° - H1 \tag{2}$$

$$z2 = \widehat{Z2A} = 90° - H2 \tag{3}$$

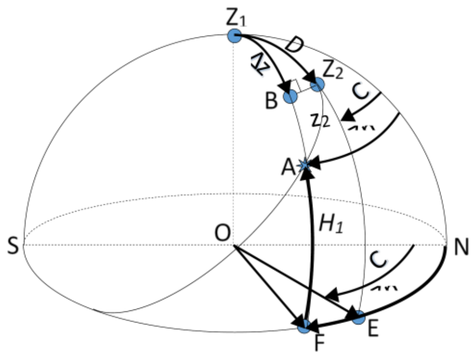

Figure 2 Geometry of the same-altitude reduction between two star sights

From point Z_2, draw a spherical perpendicular to the vertical circle of the star corresponding to the first zenith, and label the point of intersection B.

The arc Z_2B represents the projection of the horizon arc EF on the celestial sphere. As can be seen in Figure 2, the arc EF has as its value the difference between star A's azimuth (Zn) and the ship's course (C):

$$\widehat{EF} = Zn - C \tag{4}$$

The arc Z_1B represents the variation of the zenith distance (Δz) of star A. Notice that the spherical triangle Z_1-Z_2-B is formed; being very small compared to the

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celestial sphere, it can be treated as a plane triangle. As a result:

$$\widehat{Z1B} = \Delta z = -D \cdot cos\ (Zn - C) \tag{5}$$

Note: the right-hand side of the above equation is negative because the altitude increases due to the lowering of the horizon as the ship moves towards the star.

2.3 Altitude variation due to the ship's movement

Between the variation of the zenith distance of a star (Δz) and the variation of its altitude (ΔH) there is the following relation:

$$\Delta H = |\Delta z| \tag{6}$$

where ΔH = |Δz| represents the variation of altitude due to the movement of the vessel between the two observations, over the travelled distance D. As a result, the above equation can take the following form:

$$\Delta H = D \cdot cos(Zn - C) \tag{7}$$

To calculate the distance between the two dead reckoning positions, the following formula is used: Distance (D) = speed (S) × time (ΔT). For time, the following relation is used:

$$\Delta T = CT2 - CT1 \tag{8}$$

$$\Delta H = S \cdot (CT2 - CT1) \cdot cos\ (Zn - C) \tag{9}$$

Considering the speed in knots and ΔT in minutes, the above relation becomes:

$$\Delta H = \frac{S}{60} \cdot (CT2 - CT1) \cdot cos\ (Zn - C) \tag{10}$$

where S/60 represents the speed in nautical miles per minute.

The algebraic sign of the altitude variation (ΔH) is positive (+) if the vessel moves toward the star, and negative (–) if the ship moves away from the star.

The distance D may also be determined using log indications (LI); in this case the altitude variation is:

$$\Delta H = f \cdot (LI2 - LI1) \cdot cos(Zn - C) \tag{11}$$

Note that Zn – C corresponds to the relative bearing of the star (RB).

- **Practical considerations**

– the distance D is determined using the formula D = S × T, or from the difference between the log indications for the two observations, multiplied by the log correction factor (f):

$$D = f \cdot (LI2 - LI1) \tag{12}$$

– time T is given by the difference between the chronometer indications for each of the two observations (see formula (8));

– the azimuth (Zn) is determined following the algorithm for calculating the elements of the astronomical LOP;

– the term cos(Zn – C) – the relative bearing – has the following algebraic sign:

– plus (+) if the relative bearing (Z_n – C) is between 0–90° and 270–360° (the star is forward of the beam);

– minus (–) if the relative bearing (Z_n – C) is between 90–270° (the star is abaft the beam).

– the altitude variation (ΔH) reaches its maximum when the star is in the bow or astern, and equals zero when the star is abeam.

- **Working algorithm**

– make the observation at the first star and note the sextant index, chronometer time (CT_1) and log indication (LI1);

– make the observation at the second star and note the sextant index, chronometer time (CT_2) and log indication (LI2);

– determine the DR position for the second observation;

– calculate the travelled distance (D) between the two observations;

– calculate the elements of the first astronomical LOP_1: azimuth (Zn_1) and intercept (a1);

– calculate the altitude variation of the first observation (ΔH) due to the travelled distance D;

– apply the altitude variation to the first intercept to obtain the reduced intercept a'1 (a'1 = a1 + ΔH); the first LOP elements are then LOP_1: Zn_1, a'1;

– calculate the elements of the second astronomical LOP: LOP_2: Zn_2, a_2;

– plot the two LOPs; their intersection gives the astronomical fix of the vessel;

– extract the geographical coordinates of the astronomical fix.

3. RESULTS AND DISCUSSION

The effectiveness of the same-altitude method depends on minimising the errors introduced by dead reckoning between observations. The time interval between the two sights should therefore be sufficiently short, and the vessel's speed and course must be known precisely. When properly executed, the method provides a reliable and elegant means of obtaining a navigational fix using fundamental astronomical principles. Since both altitude measurements are taken at similar angles

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and with the same instrument, systematic errors (index error, dip) tend to cancel out.

Astronomical observations are most effective during astronomical night, when the Sun is more than 18 degrees below the horizon, eliminating residual twilight and providing the darkest possible sky. In most regions this window begins approximately 1.5–2 hours after sunset and ends about 1.5–2 hours before sunrise, maximising the visibility of faint celestial objects and minimising interference from scattered sunlight.

Stars such as Denebola and Arcturus are particularly well suited to this method due to their brightness, well-known positions and wide separation in right ascension, offering flexibility in timing and redundancy for verification. The technique also enhances navigational self-sufficiency, as it does not depend on electronic aids or satellite systems, remaining a valuable and dependable alternative in traditional celestial navigation – especially on long ocean passages, where backup methods are essential for navigational safety.

The algorithm calculus is carried out according to [2]–[11].

On July 14, 2021, at chronometer time CT = 19h46m23s, the star Denebola was sighted. The sextant altitude was Hs = 64°17.7'. Height of eye is 14 m, index

correction IC = +1.5', and chronometer correction CC = +1m12s. Log indication is LI1 = 1234.5 and the log correction factor is f = 1.00; all data are available on board.

After a time interval, at chronometer time CT = 19h58m59s, in DR position Lat = 38°12'N, Lon = 040°51'W, the star Arcturus was sighted. The sextant altitude was Hs = 63°03.4'. The true course was TC = 105° and the speed S = 16 kts. Log indication is LI2 = 1237.9.

Note: the first altitude will be reduced to the zenith of the second observation (Table 1).

Table 1. Meridian angle (t) and declination (Dec)

Date	July 14, 2021	July 14, 2021
Body	Denebola	Arcturus
CT	19h46m23s	19h58m59s
CC	+ 1m12s	+ 1m12s
UT	19h47m35s	20h00m11s
IC	+ 1.5'	+ 1.5'
Alt. Corrn	- 7.2'	- 7.2'
Sum	- 5.7'	- 5.7'
Hs	64°22.5'	63°03.4'
Ho	64°16.8'	62°57.7'
GHA γ (20h)	217°51.3'	232°53.7'
Increments (m/s)	11°55.7'	0°02.8'
Total GHA γ	229°47.0'	232°56.5'
SHA	182°28.0'	145°50.4'
GHA*	412°15.0'	378°46.9'
Lon (E/W)	-040°51.0'	-040°51.0'
LHA*	371°24.0'	337°55.9'
360°	-360°	-359°59.1'
t (E/W)	011°24.0' W	022°04.1' E
Tab. Dec.	N14°27.3'	N19°04.5'

3.1 LOP 1 – Deneb Computed altitude (H_c) and intercept (a) computation.

The following formula is used to determine the computed altitude (H_c) (Table 2):

$$Hc = \underbrace{\sin Lat \,.\, \sin Dec}_{parta} + \underbrace{\cos Lat \,.\, \cos Dec \,.\, \cos t}_{partb} \tag{13}$$

Table 2. Altitude computation (Hc) – Deneb

E Lat	38°12.0' N	sin Lat	0.618408395	cos Lat	0.785856893
Dec	N14°27.3'	sin Dec	0.249619546	cos Dec	0.968343990
tW	11°24.0' W			cos t	0.980271175
Ho	64°16.8'	part a	0.154366823	part b	0.745966562

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Hc	64°12.1'	part b	0.745966562		
Intercept (a)	+ 4.7'	sin Hc	0.900333384		
		Hc	64°12.1'		

Used formulas:

$$sinZ = \sin t \cdot secH_c \cdot cosDec \tag{14}$$

$$sinH_{PV} = \sin Dec \cdot cosecLat \tag{15}$$

The zenith angle given by this formula has a quadrantal size (Table 3).

Table 3. Zenith angle value computation – Deneb

tW	11°24.0' W	sin t	0.197657340	HPV	
Hc	64°12.1'	sec Hc	2.297789525	sin Dec	0.249619546
Dec	N14°27.3'	cos Dec	0.968343990	cosec Lat	1.617054373
Lat	38°12' N	sin Z	0.439797599	sin HPV	0.403648378
HPV	23°48.4'	Z	26°05.5'	HPV	23°48.4'
Dec same name as Lat		Z	26°.1	180°	180°.0
Dec < Lat	Hc > HPV	Z	SW 26°.1	Z	+26°.1
				Zn	206°.1

The following tables (Tables 4–10) help to establish the quadrant of the horizon in which the body is sighted.

Table 4. Quadrant establishment

Name of Dec	Magnitude of Dec	Size of Hc	Origin (1st letter)	Direction (2nd letter)
1	2	3	4	5
contrary to Lat	-	-	contrary to Lat	same name as meridian angle
same name as Lat	Dec < Lat	Hc > HPV	contrary to Lat	same name as meridian angle
same name as Lat	Dec < Lat	Hc < HPV	same name as Lat	same name as meridian angle
same name as Lat	Dec > Lat	-	same name as Lat	same name as meridian angle

Notes: – HPV represents the altitude of the celestial body in the Prime Vertical, computed using the following formula:

$$sinH_{PV} = \sin Dec \cdot cosecLat \tag{16}$$

To convert the zenith angle (Z) into azimuth (Zn), the following conversion table (Table 5) must be used:

Table 5. Conversion of zenith angle to azimuth

Z	Zn
Z = NE ... °	Zn = Z
Z = SE ... °	Zn = 180° – Z
Z = SW ... °	Zn = 180° + Z
Z = NW ... °	Zn = 360° – Z

Altitude reduction (Tables 6 and 7):

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Table 6. Altitude reduction – variant 1

LI2	1237.9	Zn	206°.1		
LI1	1234.5	C	105°.0		
Diff.	3.4	(Zn-C)	101°.1		
x f	1.0			a1	+4'.7
Dist	3.4	cos (Zn-C)	x (-0.192521)	ΔH	-0'.7
				a'1	+4'.0

Variant:

Table 7. Altitude reduction – variant 2

S/60	16/60	0.26 x	Zn	206°.1		
CT2	19h58m59s		C	105°.0		
CT1	19h46m23s		(Zn-C)	101°.1		
CT2 - CT1	00h12m36s	13m x			a1	+4.7
cos (Zn-C)	cos 101°.1	-0.192521 =			ΔH	-0.7
ΔH		-0.7			a'1	+4'.0

$$LOP1\begin{cases}Zn1 = 206°,1\\ a'1 = +4',0\end{cases}$$

3.2 LOP 2 – Arcturus

Computed altitude (Hc) and intercept (a) computation.

Used formula:

$$Hc = sinLat * sinDec + cosLat * cosDec * t$$

Part a Part b (17)

Table 8. Altitude computation (Hc) – Arcturus

E Lat	38°12.0' N	sin Lat	0.618408395	cos Lat	0.785856893
Dec	N19°04.5'	sin Dec	0.326805556	cos Dec	0.945091598
tE	022°04.1' E			cos t	0.926736424
Ho	62°57.7'	part a	0.202099300	part b	0.688293395
Hc	62°55.4'	part b	0.688293395		
Intercept (a2)	+ 2.3'	sin Hc	0.890392694		
		Hc	62°55.4'		

Zenith angle (Z) and azimuth (Z_n) computation.

Used formulas:

$$sinZ = sin\ t \cdot secH_c \cdot cosDec \qquad (18)$$

$$sinH_{PV} = sin\ Dec \cdot cosecLat \qquad (19)$$

The zenith angle given by this formula has a quadrantal size (Table 9).

Table 9. Zenith angle value computation – Arcturus

tE	22°04.1' E	sin t	0.375712125	HPV	
Hc	62°55.4'	sec Hc	2.196869369	sin Dec	0.326805556
Dec	N19°04.5'	cos Dec	0.945091598	cosec Lat	1.617054373
Lat	38°12' N	sin Z	0.780069587	sin HPV	0.528462354
HPV	N45°21.5'	Z	51°16.0'	HPV	31°54.1'
Dec same name as Lat		Z	51°.3	180°	179°.10
Dec < Lat	Hc > HPV	Z	SE 51°.3	Z	-51°.3
				Zn	128°.7

The following table helps to establish the quadrant of the horizon in which the body is sighted (Table 10).

$$LOP2\begin{cases}Zn2 = 128°,7\\ a2 = +2',3\end{cases} Fix\begin{cases}Lat = 38°07,1'N\\ Lon = 40°50,1'W\end{cases}$$

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The application of the same-altitude method in this context demonstrates both the theoretical robustness and practical utility of classical celestial navigation. Beyond its practical maritime application, the method also echoes a longstanding cultural and religious tradition: the use of celestial bodies to structure human activity.

Both systems – celestial navigation and Islamic prayer timing – demonstrate a profound continuity between observational astronomy and human practice, bridging scientific technique and spiritual rhythm.

They reflect an enduring human inclination to look to the sky not only for spatial orientation but also for temporal structure and metaphysical meaning.

Thus, the same-altitude method serves not only as a precise navigational tool, but also as a reminder of the deep cultural significance embedded in our observation of the cosmos.

Table 10. Quadrant establishment

Name of Dec	**Magnitude of Dec**	**Size of Hc**	**Origin (1st letter)**	**Direction (2nd letter)**
1	2	3	4	5
contrary to Lat	-	-	contrary to Lat	same name as meridian angle
same name as Lat	Dec < Lat	Hc > HPV	contrary to Lat	same name as meridian angle
same name as Lat	Dec < Lat	Hc < HPV	same name as Lat	same name as meridian angle
same name as Lat	Dec > Lat	-	same name as Lat	same name as meridian angle

4. CONCLUSIONS

This research highlights several important findings. Firstly, it emphasises that there are numerous connections between science and religion. While these domains are often seen as distinct or even conflicting, this study suggests they are not necessarily parallel or mutually exclusive; instead, science and religion can coexist and complement each other, especially when addressing various aspects of human life.

A key focus of the paper is the strong relationship between nautical astronomy and Islam. The research demonstrates how astronomical knowledge can be practically applied to support Muslim seafarers in observing their daily prayer rituals while at sea.In situations where internet access is unavailable, seafarers must rely on traditional navigational tools – such as the sextant and chronometer – as well as nautical almanacs and calculation tables. These instruments and resources enable them to accurately determine prayer times, thereby maintaining their religious duties even in isolated maritime regions. Ultimately, this study may serve as a valuable guide for Muslim seafarers, offering practical methods to uphold their religious practices throughout their voyages.

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