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Effect of the Use of Celestial Navigation Technology in Marine Navigation

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ABSTRACT
The historical development of technology used in celestial navigation is presented in this paper. As with the realization of the limitations of the earlier technology, advancements have provided solutions to provide more effective information for marine navigation. Though technology may have provided the solutions for the limitations encountered, technology is in itself still limited to address certain emergencies and threats. Thus, learning of the crude method of celestial navigation is recommended. Although this realization has been supported by the revival of the course of celestial navigation in the US Naval Academy, the need to reinforce the significance of using crude celestial navigation methods must be made.

Keywords: *Marine Navigation, Celestial Navigation*

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I. INTRODUCTION

Over the centuries, man has developed varying means of determining one's position and projecting one's directions in the vastness of the oceans. Sea voyagers of the past developed both meteorological and astronomical methods for determining locations at sea. Many tools and principles including the use of the sun and the stars for determining location and distance have been developed. The use of celestial bodies was later referred to as celestial navigation. In this area, technology and its advancements has charted a different direction than the prior conventional means used in marine navigation.

The use of navigational instruments has been proven effective in charting courses and setting directions. However, through time, their development and use have also provided certain effects and limitations. This paper aims to address the research question – What are the effects of the use of celestial navigation technology in marine navigation? This paper includes the historical development of celestial navigation technologies from the past to the present and the effects of their use through time in marine navigation. This also intends to provide insight on what had been done so that people can learn from the past and what may be done in the present or the future to address the effects and limitations provided by the use of celestial navigation technologies.

Objectives

The main objective of this research is to determine the effects of the use of celestial navigation technology in marine navigation. This paper also intends to identify the effects of the use of celestial navigation technologies from the past to the present. Moreover, this should provide insight into the effects of its use so that marine navigators could better understand and use celestial navigation technologies.

Scope and limitations

The paper provides a historical background of navigational technologies with special emphasis on celestial navigation. The earlier tools and principles in celestial navigation are included aside from the more modern technological advancements. This is intended to provide a greater understanding of the effects of their use in the course of time. Navigational technologies in aviation are mentioned merely as they also apply in marine navigation. The effects of the use of these technologies are limited only to the marine navigators and the naval force as an institution.

II. HISTORICAL DEVELOPMENT OF MARINE TECHNOLOGY

Over history, ship navigators have relied upon astronomical clues to find their direction. Voyager accounts like the works of Homer, Herodotus, the Bible, and the Norse sagas had indicated references to the sun and stars as guides for ships (Encyclopedia Britannica, "Navigation Technology," par. 8). In these accounts, the constancy of the movements of the celestial bodies had been used as a basis for moving directions. The daily natural phenomenon of the sun's rising and setting has provided the directions of East and West. The casting of the shadows at noontime has determined the North and South directions. Similarly, at night, the rising and setting of the stars give directional clues for the East and West.

Through time, man has learned to develop simple tools to find directions and has showed increased accuracy in doing so. The use of the polestar has determined the latitude. Based on this knowledge, the quadrant, astrolabe, and cross staff have been created as useful instruments for sea navigation.

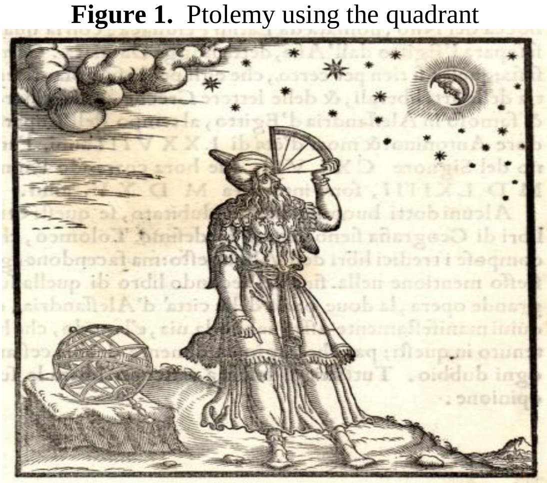
Celestial Navigation. Celestial navigation is the science or principle used for establishing the navigator's position by the discerned locations of celestial bodies (Encyclopedia Britannica, "Celestial Navigation," par. 1; Garvin, 7). During a given time, this celestial body is at the peak of any specific position on the Earth's surface, referred to as the ground position. This ground position can be provided through celestial coordinates. As the celestial line of position is established, a concept uncovered by Sumner in 1837, the navigator measures the altitude of the celestial body using a sextant or bubble octant and identifies through this the dead-reckoning position. From there, calculations are derived to provide the navigator's position. St. Hilaire's intercept method which was developed in the 19^{th} century translated these concepts into nautical miles (Encyclopedia Britannica, "Celestial Navigation," par. 1). Other methods like ex-meridian and longitude by chronometer also provided similar nautical distance information.

Celestial navigation has not been restricted to be defined involving only the use of tools in the early centuries like sextants, almanacs, and tables (Garvin, 7). In more recent years, calculators or computer programs are described to provide the predictions of the geographic positions of the sun, stars, or the moon. The following section describes tools used for celestial navigation.

Quadrant. Medieval astronomers developed the quadrant, which is an instrument determining up to 90^0 angles. For marine navigation, the quadrant should indicate the destination's latitude as the navigator sailed north or south. The earliest quadrants were not graduated but included the latitudes of the most frequented destinations written directly on the quadrant's limb (May, 1973). Obviously, this would have limited identifying new locations or latitudes as the ships went to uncharted locations. Moreover, quadrants only identify north and south directions.

The use of the quadrant required two persons – one holding the instrument in its correct position and observing the celestial body and the other person taking the reading. Accuracy was also limited as the quadrant was small. The wind or the observer's movements also affected the plumb bomb, the suspended line from the center of the quadrant's arc which helped identify the 90^0 angle. With a moving ship, staying steady would be nearly impossible (May, 1973). Figure 1 shows an image of how Ptolemy, the astronomer-mathematician, used the quadrant. With this depicted stance and use of the quadrant, the concern on keeping steady on a moving ship is realized.

Figure 1. Ptolemy using the quadrant



Astrolabe. The common astrolabe is an astronomical instrument which identifies the position of celestial bodies. It illustrates how the sky looks at a particular time and place by drawing the sky on the astrolabe and marking the positions of the sun, moon, planets, or stars (Morrison, par. 2). Specifically, the mariner's astrolabe is a ring denoted with degrees to measure the altitudes of celestial bodies. The angle of a particular celestial body above the horizon was measured to identify the latitude of the observer (Garcia, 249). On land, the astrolabe could more effectively identify the latitude. Similar to the quadrant, there was also difficulty in determining the latitude on the deck of a ship or due to the effects of the wind. Figure 2 shows a picture of the mariner's astrolabe.

Figure 2. Mariner's astrolabe

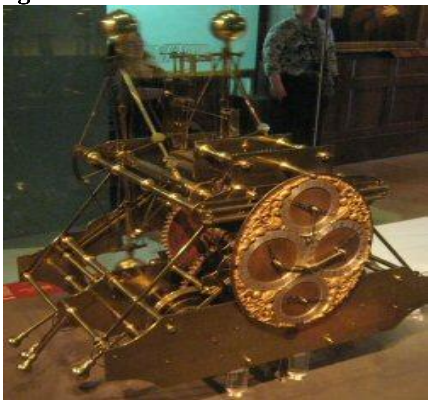
Cross staff. According to Cline (par. 1), the cross staff is a long staff with a perpendicular vane which glides back and forth. It has graduated measurements which were determined through trigonometric calculations. Angle measurements can be made by holding it so that the ends of the vane are horizontal with the points to be determined. The angles between the stars or their altitudes can be measured. The same altitude measurement could be taken for the sun. The staff was later adjusted into degrees for use at sea. Similarly, as this is held by the navigator, keeping a steady hand on a rocking ship may be difficult. The cross staff was long and impractical; thus, the marine navigators put in more vanes so that the length of the staff would be shortened. Another problem for its use is that during cloudy skies or looking directly at the sun, the cross staff was rendered useless.

Overall, the quadrant, astrolabe, and cross-staff designs were limited in terms of providing accurate measurements. Their uses during the ship's motion at sea and during certain atmospheric conditions were impractical.

Almanacs and tables. Establishing the latitude had not been as difficult compared to determining the longitude since measuring the Sun's altitude at noon, or any tabulated star which crossed the local meridian provided a clue to the ship's distance (Encyclopedia Britannica, "Navigation Technology," par. 32). Meanwhile, Ephemerides provided the principles for determining longitude measurements through the lunar distances. However, because of the tediousness of calculations, almanacs and tables were then produced to provide the seafarers with astronomical data. Contained in the almanacs were the positions of 57 selected celestial bodies. They provide a crude determination of the longitude based on the behavior of the moons of the Earth and Jupiter (Encyclopedia Britannica, "Navigation Technology," par. 31). They also specify the Sun's, moon's, planets' and the first point of Aries' positions relative to the Earth's surface for each 60 minutes of the year (US Naval Observatory, "Data services"). A probable limitation is that almanacs and tables are text listings and are published which require navigators to be familiar with its contents. Another limitation is that these tools are made of paper, which may be susceptible to the water surroundings. Moreover, almanacs and tables are not used alone as the navigators also need a chronometer and a sextant (US Naval Observatory, "Nautical Almanac").

Chronometers. The marine chronometer was developed to resolve longitude determination issues. As the time of the moon's eclipse was based on longitude, the reading of a reliable clock which kept the time of a known meridian was necessary (Encyclopedia Britannica, "Navigation Technology," par. 34). But, there was no accurate marine timekeeper available then. Clocks on land were accurate only for one to two seconds over several days interval. On board a ship, the clock was undependable due to bouncing waves, corrosive salt sprays, and changing conditions of humidity, pressure, and temperature. These conditions prompted the invention of the marine chronometer by John Harrison during the 1700s (Encyclopedia Britannica, "Navigation Technology," par. 34). Please refer to figure 3 for Harrison's chronometer.

Figure 3. Harrison's marine chronometer



With the use of the marine chronometer, combined with sextant sightings of the sun and stars, increased precision was provided for a sea voyage. However, not all ships were able to carry these as they were expensive at the time (Hall, 1862 in Project Gutenberg). Ships during those times had to stop by shortly at Greenwich River Thames to observe a time ball and synchronize their chronometers at 1 pm (Brooke, n.d.). Furthermore, routine checking through lunar or solar observations was necessary for the chronometer to ensure accuracy (Bowditch, n.d.). The gadget was also required to be sheltered and mounted below deck for protection and needed a hack watch to do the astronomical observations. The chronometer also requires regular winding at the same time each day, and it also needs cleaning and overhaul every three years for proper maintenance (MSI, 269). Though the chronometer's accuracy, all the conditions for its upkeep can also appear to be its limitations.

Sextant. The sextant is an instrument which measures the angle between the horizon and a celestial body (Encyclopedia Britannica, "Sextant", 1999). It is identified as a variant of the astrolabe (Strongman, 66). The measures provide the latitude and longitude through an arc calibrated in degrees, a movable radial arm, and a telescope. The distance of the celestial body is based on the sextant's graduated arc. As this also requires the sighting of a celestial body, keeping the instrument steady and with cloudy skies, the sextant would also be unreliable.

The use of the sextant requires a considerable amount of skill and practice, aside from a good technique (MSI, 266). Errors in using the sextant may come from the improper rocking of the sextant, inaccurate judgment of tangency, use of a false horizon, presence of a subnormal infraction, the wrong height of eye, wrong time, incorrect determination of the index correction, unadjusted sextant, and computational errors (MSI, 266). Aside from these, navigators tend to estimate the precision of their examination from the size of the figure made when the lines of position are marked. This is regarded imperfect as these do not consider individual and constant errors. There are also other reasons for inaccurate use which are beyond the navigator's control.

The development of these tools was further supported by the discovery of routine trigonometric procedures, dead reckoning, and compasses and logs. The Bygrave position-line slide rule is an instrument which aided in the fast trigonometric calculations required in celestial navigations. This was an early calculator to assist the navigator perform calculations in a less conducive environment for such a mental task (Garber, par. 8). Figure 4 shows a picture of this slide rule.

Figure 4. Bygrave position-line slide rule

The development of air and space travel has also contributed to the use of "radio communication and radio navigation, electronic instruments, and high-speed digital computers" (Encyclopedia Britannica, “Navigation Technology,” par. 1). The same technological innovations have been beneficial to marine travel. Although these do not directly use celestial bodies, the principles of their use may have been based on these earlier instruments.

III. MORE RECENT MARINE NAVIGATION SYSTEMS

With the introduction and advancement of technology, satellite navigation or global positioning systems (GPS) have made celestial navigation unnecessary (Garvin, 7-8; Kaplan, par. 38; GPS, n.d.) Garvin (7) has considered celestial navigation as a dying art. In 1998, the course on celestial navigation was terminated as the reliability of the sextant, and satellite-linked computers increased.

The following technological developments have deemed celestial navigation redundant and the earlier tools such as the sextant obsolete. Additionally, budget cuts in military training even more justified the removal of celestial navigation as a course (Garvin, 11). The Naval Academy had also provided training using computers in navigation. Prior to the introduction of GPS, there were other navigation systems like Omega, TRANSIT, LORAN, and VOR/DME.

Omega. In 1971, Omega was developed as a global-range radio navigation system. Through the use of very low-frequency radio signals of 10.2 kHz, 13.6 kHz, and 11.333 kHz and a fourth unique frequency, ships were able to establish their positions (Proc, 2012, par. 26). The Omega provided a four-mile accuracy in marking a position. The system was operated by the United States in collaboration with six other countries including Argentina, Australia, France, Japan, Liberia, and Norway (Proc, par. 25). The collaboration made possible the transmission of a network of fixed terrestrial radio beacons through a receiver. But, during the introduction of GPS in the 1990s, Omega was made obsolete in 1997.

TRANSIT. The first satellite navigation system, called the TRANSIT or NAVSAT, was operated in 1958. This system provided the US Navy an accurate location. It is also a navigation system and equipment used for hydrographic survey and geodetic surveying (Johns Hopkins University Applied Physics Laboratory, 1998). The system was used for 32 years and was also made obsolete by GPS systems.

LORAN and VOR/DME. The same obsolescence for LORAN, a ground-based navigation system for the US Coast Guard, was declared in 2008 (GPS, par. 1). A similar decision was made for VOR/DME, a VHF omnidirectional range (VOR) and distance measuring equipment (DME), a radio navigation station for aircraft, but it was also used for the marines. Before its phase out, this system was made practical due to the low-cost solid state receivers.

Global Positioning Systems. Navigation started using GPS in 1996 (Garvin, 7). GPS is now considered more inexpensive and more accurate for navigation first in aviation and then later by marine navigation. Other navigation or position systems are regarded inferior to GPS due to this. Also, a GPS is regarded more efficient; however, it has only a life span of eight years (Garvin, 5). Thus, replacements would have to be launched to keep the GPS continuously operational.

As with any technology today, its use is subject to security threats. Satellite systems are subject to computer malware, electromagnetic pulse attacks, and jamming (Peterson, 2016). Kaplan (par. 2) cited the need for contingencies for GPS as this has operational vulnerabilities. Garvin (12) reported that GPS signals had been jammed sometime in 2010, which had presented grave threats for the U.S. military. At this instance, Garvin (12) suggested the accuracy of digital maps as an alternative.

Inertial Navigation Systems. An alternative to GPS so that a backup system is in place is inertial navigation systems. Navy ships and aircraft commonly have this onboard. However, they are accurately only for dead reckoning. Accuracy is also not guaranteed for longer time periods (Athena Navy, par. 6). Furthermore, they need regular alignment with an external reference system, which could be a GPS. Kaplan (par. 3) remarked that still, inertial navigation systems are inferior backup systems as they are not independent of the primary navigational system. This means that these systems do not satisfy the Navy's navigation policies as inertial navigation systems still require inputs from the GPS, the primary navigation system. During a functional or operational failure of a GPS, an inertial navigation system would not work as well.

The Resurgence of Celestial Navigation

Nevertheless, prudence required the knowledge of celestial navigations if in case electronic navigation fails. The U.S. Navy has deemed this knowledge important since celestial navigation can be used independently of ground assistance, has a global coverage, and does not send off signals detectable by enemies (U.S. Air Force). In 2015, renewed interest in courses in celestial navigation sparked as the reliability of GPS systems was questioned due to the threats of potential hostile hacking (Prudente, par. 3). Celestial navigation is regarded to be an important backup system. Lt. Alex Reardon of the U.S. Naval Academy aptly put the need for celestial navigation as "redundancy is the best policy" (Peterson). Additionally, Kaplan (par. 2) reiterated the Navy navigation policies as to have an alternate means of position determination, which should be independent of a primary means. Kaplan (par. 4) believed that the use of celestial bodies is a more viable alternative as this is truly independent of GPS and it is more basic and accurate. During electronic systems failure or electrical power breakdown, improvisation, that is, through the use of basic principles, paper charts, and a sextant may be called for (Garvin, 2). Complete dependence on electronic systems is risky, particularly during emergencies. Besides, celestial navigation is free from spoofing (Navigation Technology, 16).

With the U.S. Naval Academy's continued offering celestial navigation (CELNAV) in 2015 (Arneson, par. 5), competency certificates in Navy training required this course. Skills required for celestial navigation have remained constant for centuries. Students in the Naval Academy would have to master the use of hand-held marine sextants and sight reduction techniques. Almanacs and other sight reduction tools are now easier to use. The course in celestial navigation equips students with knowledge of the positions and motions of celestial bodies. Students are also given training in the "relationship between geographical and celestial projections and altitude differences, and how to determine plotting differences when working with observed altitudes of the various bodies" (Garvin, 12). Moreover, knowledge is supplemented by cyber classes that equip students with the knowledge of the vulnerability of electronic systems as well as the effects of cyber threats (Arneson, par. 8).

Meanwhile, celestial navigation could be used to align with inertial navigation systems. The integration of celestial navigation and inertial navigation systems is not a novel concept. Celestial navigation may not be feasible during a cloudy day, however inertial navigation systems are regarded as "excellent bad-weather flywheel" (Kaplan, par. 4). Moreover, the method has certain limitations. First, celestial navigation has low accuracy. Second, the horizon must be visible. Third, the data rate is low. Fourth, data collection may be subject to errors as the navigator is also beset by other duties. Fifth, the celestial bodies which may be observed are limited to the sun and the bright stars. Sixth, there are also restrictions on sky area or altitude used. Though celestial navigation is less accurate by several nautical miles, the reading may be just as good for "sanity checks" according to Kaplan (par. 5). Thus, celestial navigation is useful during emergencies.

In 1999, Kaplan (par. 6) indicated that there are fixes to the limitations of celestial navigation. These limitations could be addressed by the computational procedure and observational hardware. Mathematically, since human navigators may be prone to errors, computer programs were suggested to perform the computations. The Stella (System to Estimate Latitude and Longitude Astronomically) Project had provided many alternatives for the basic algorithm (par. 12). Despite this, seafarers are still required to carry a sextant and try to derive lines of position which may be subject to difficult conditions (Athena Navy, 6).

Mathematical approaches have been attempted by a number of researchers. An example is the development of genetic algorithms in solving celestial navigation fix problems by Tsou (53). He had acknowledged the benefits of the use celestial navigation although at the same time recognized its limitations. Celestial navigations cannot be supplanted by GPS because of its efficiency, reliability, independence, and being detection-free. An artificial intelligence derived genetic algorithm was formulated by Tsou to address snags in celestial navigation fix. Tsou's approach provided no complex mathematical steps, the prevention of converging toward local optima, and increased flexibility in practice and fast convergence toward the definitive location approximation. His genetic algorithm approach can be used for a single or multiple celestial bodies. This method can confirm if the GPS is generally working (Tsou, 59).

In the meantime, an accurate program should allow the navigator to focus on improving their observational habits and sighting (Kaplan, par. 8). During that time, research had provided the algorithmic approaches which were already embedded in the computing software programs for a two-celestial-body fix. However, Kaplan commented that this approach may not prove mathematically independent and that the solutions do not apply for three or four sightings (par. 9). With greater than two sightings, the problem is more than defined and least squares method can be applied, especially the technique developed by de Wit and Severance, a more mathematically straightforward least-squares formulation (par. 11). A few more methods were identified to offer refined solutions like Janiczek and an extension method published by Metcalf (Kaplan, par. 11). In the computation, Kaplan indicated that since the observer's position varies while making the observations, the use of algorithms needed the transformation of a moving-observer situation to a fixed-observer problem (par. 13). Today's computer systems should have been better refined in the light of these observations.

Lately, the usefulness of celestial navigation is further supported by highly sophisticated technology. New hardware for space systems, those used by the aerospace engineering community, and star trackers is deemed beneficial for marine navigations. Ironically, the need now for celestial navigation should fill in the limitations of technology. Global navigation satellite systems denial may include a variety of factors. A few of these include aerial damage, accidental interference, malfunctioning tracking systems, solar flares, and hostile hacking (Naval technology, par. 11). Many of the devices on the ship would be rendered ineffective when the GNSS is obstructed. A more deceptive threat is that a good hacker can redirect a ship without automatic detection. GNSS are prone to simple, low-tech jamming as their signals are of very low power (Naval technology, par. 12). Even at a 1.5-watt transmitter, the GPS becomes unreachable for 30 km. This has shocking implications on rendering the ship unable to navigate.

IV. AUTOMATED CELESTIAL TECHNOLOGY

At the beginning of the space age, automated celestial technology has been utilized for satellites, missiles, and space exploration for navigational purposes (USNO and SPAWARSYSCEN SD, 3). Polaris and Trident are examples of strategic missile systems which used compact star trackers. Later versions of these systems offer the precision of sub-arcsecond (<1 μrad). Similarly, the Space Shuttle, as well as satellites, contains a number of star trackers. Capacities have improved from single stars to multi stars. Models of this celestial observing systems integrate INS such as those found on a few certain aircraft. The LN-20 gimbaled star tracker, for instance, has a short Cassegrain telescope which provides the observation of 57 bright stars (USNO and SPAWARSYSCEN SD, 4). A view of 6 arcminutes is provided with a star fix at an interval of 110 seconds.

The new technology has not yet been used for surface operations (USNO and SPAWARSYSCEN SD, 5). These new systems are simpler, smaller, more efficient, and more reliable as they contain more quantum efficiency detectors. Data stars are in the thousands unlike tens in the old technology. They may also be cheaper, but the small production volume has kept the costs high. Old and new celestial technology systems are compared in the following Table 1.

Table 1. A comparison of old and new celestial technology

Old Technology	New Technology
Gimbaled	Strapdown (few or no moving parts)
Small field of view	Wide field of view
Single star observations	Multiple simultaneous star observations
Photomultiplier tube or similar detectors	CCD (silicon array) detectors
Programmed observation sequence	Automatic star pattern recognition

Newer versions of star trackers are now lightweight and integrated with INS systems of ships. More accurate and large data of star positions at less than 100 feet can be provided day or night (USNO and SPAWARSYSCEN SD, 5).

Cloud cover as one of the major limitations using celestial observation is resolved by the following suggestions. To obtain a clear line of sight, certain bands in the far red or close to the infrared section of the spectrum can be observed. In this area, the skies are more transparent. Though, at sea, this problem is more prevalent. Familiarity with the use of the equipment through the number of years use, supplemented by an astro-inertial system, provides that brighter stars and planets can be viewed through the cirrus. Again, the INS fulfills as the bad-weather "flywheel." With this, the stellar fix can be carried forward awaiting getting hold of the new observations.

Automated celestial trackers and INS are an effective complements to each other. The following characteristics or features of INS and celestial technologies illustrate this

INS is self-contained and has no coupling to an external reference system; celestial provides a direct link to the most fundamental inertial reference system available. INS units require initial alignment using positioning data from another source; celestial is completely autonomous. INS accuracy degrades with time from initial alignment; celestial fix accuracy is not time dependent. INS units are oblivious to the weather; celestial is sensitive to cloud conditions. Yet, despite their differences, both INS and celestial are passive, jam-proof, and in operational use are not dependent on shore or space components (USNO and SPAWARSYSCEN SD, 6).

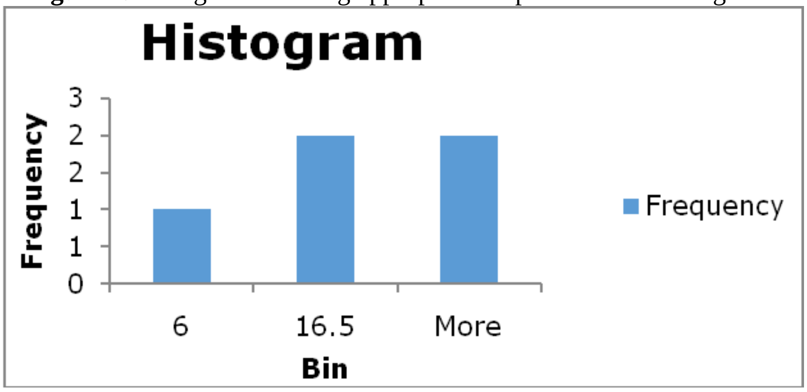
Another available automated celestial navigation systems is the CosmoGator. This multi-part system has a gyro-stabilized and actuated camera (Athena Navy, par. 7). Cameras can be guided by ephemeral data from existing systems like STELLA. The features of this system include the ability to take steady and accurate measurements more the tenth degree of what a sextant can provide. The data would then be put in the navigation computer systems. Even with the loss of GPS, an automatic shift to inertial navigation systems occur and runs accurately for 48 hours. The error of the ship's position is estimated at ≤ 25 meters. Prior to the CosmoGator, DayStar was used but proved unsuccessful due to the lack of necessary technology (Athena Navy, par. 9). With these latest technological advancements, conventional celestial navigation systems' limitations are addressed, and their reliability during cases of emergencies is strengthened.

V. EFFECTS OF CELESTIAL NAVIGATION TECHNOLOGY

This section is an illustration of the effects of celestial navigation technology as described in the research by Garvin. This was the only study found to have focused on the effects of the use of celestial navigation technology. The context of the study is to assess the need for the continued use of celestial navigation. In this study, 90 subjects U.S. Army Transportation Corps were involved in determining the need to continue the celestial navigation course. More relevantly, this paper covered the effects of the celestial navigation. The study included the use of celestial navigation technology as the research was conducted in 2010, where celestial navigation technology is available and integrated into the training of Marine Deck Warrant Officer Basic Course (MDWOBC). Garvin identified the celestial navigation utilization by these students and their perceptions and regard about the course.

Research findings reveal that the majority, 34.6%, were neutral about using the appropriate steps in computing for the ship's position using celestial navigation; while there were 26.9 percent who agreed. The mean average on the Likert scale was 2.53 out of a high rating of 5. The distribution of the responses here shows a relatively flat histogram, indicating that there were small variances among the responses, thus depicting frequencies of almost similar proportions. There was not yet a highly significant determination of using the steps in the celestial navigation fix. Figure 5 shows this histogram.

Figure 5. Histogram for using appropriate steps in celestial navigation



Subjects were also asked to indicate the level of their agreement with the statement - Every time I have been out to sea, I used celestial navigation to check the accuracy of my ships compass. The sizeable number of responses were for agreed with 33.3% of the respondents and 32.0 percent who disagreed. The mean rating on the Likert scale was 2.74 and the researcher labeled this to indicate an overall neutral response. This implies that the respondents were divided in practicing actually what is part of the basic requirements for using celestial navigation.

The preference of usage the electronic means of navigation over celestial navigation during a voyage was also determined from the participants of the study. The majority of the respondents or 35.9 % indicated a disagreement which means that participants did not only use the electronic means of navigation and did acknowledge their use of celestial navigation while at sea. The study provided a mean of 3.08 and categorized this as a neutral response on the Likert scale. Despite that 35.9 % comprised of the majority, about 28.2% of the respondents also agreed. This resulted in a general neutral rating. Thus, mariners were divided in the regard for using less often celestial navigation than the electronic means of navigation.

The research findings also showed that majority of the respondents or 44.9% agreed that the GPS is prone to errors (Garvin, 40). Despite this, the same proportion of mariners preferred the use of GPS over celestial navigation. A discrepancy in the specific responses of the mariners is established from the earlier concept of preference of electronic means over celestial navigation. Although the majority of the respondents agreed to use the celestial navigation, still a greater majority prefers to use GPS despite its limitations.

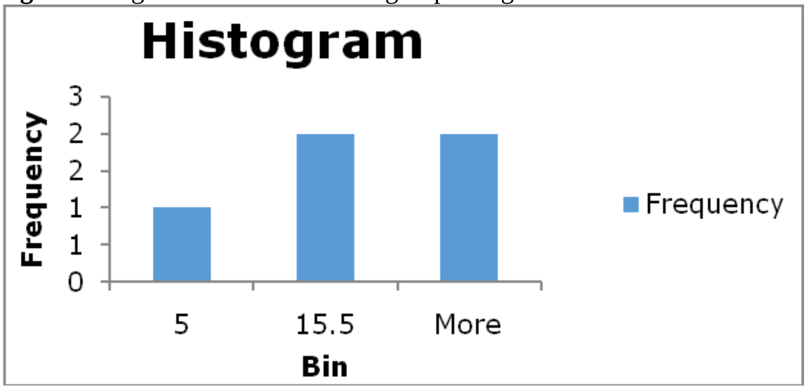
As to the extent of enforcing the use of celestial navigation by the vessel masters, subsequently requiring the watch officers to use celestial navigation while at sea, respondents indicated another overall neutral response of 3.05. Although 38.06% of the respondents agreed that they required their watch officers to use celestial navigation during a voyage, there were also 25.64% who disagreed and 24.36% who answered neutral. Thus, vessel masters are also divided in enforcing the use of celestial navigation.

A probable contributing factor in the division of perceptions for the use of celestial navigation is indicated by the regard for this navigational method as old-fashioned and outdated. Respondents were asked to rate their regard for celestial navigation, and 29.49% disagreed and a similar percentage of 20.51% was indicated for both strongly disagree and neutral responses (Garvin, 35). The overall mean rating is 2.74. This was interpreted that there is a disagreement that celestial navigation is obsolete.

The research further asked the respondents of the desirability of continuing the use of celestial navigation. A greater majority, that is 57.41% of the respondents, agreed that there is a need to continue celestial navigation (Garvin, 35). Moreover, the responses were additionally supported with the reasoning that this is basic to the mariner's knowledge.

The perception of the respondents regarding the lowering of passing scores for celestial navigation in the license exams is also indicated. The respondents were once again split in their perceptions. There were 34.2% of the respondents for both those who indicated that this was a bad idea and those who specified that lowering the scores is good (Garvin, 36). A supporting reason for the latter was that not all technology is bad. Figure 6 shows the frequency of this item's responses. A similar proportion of the responses may be noted which represents the perceptions of the respondents.

Figure 6. Agreement to the lowering of passing score for the license exams



A probable obstacle for the increased use of celestial navigation is the perceived difficulty and limitation of its use. The majority of the mariners in this study, about 27.40%, indicated "that they would use celestial navigation more if it were easier, faster, less dependent" on the weather, and if the vessel master required it (Garvin, 40). However, about 26% of the respondents hesitated to answer this question. This finding may be linked to the mariners' perceptions of how they performed the skills required in celestial navigation. About 34.62% of the respondents indicated that they were able to use the proper calculations required. This is also supported by the findings that majority of the respondents or 33.3% found the mathematics required extremely challenging. On the one hand, there were 26.92% percent of the respondents who were able to demonstrate their skills in the calculations. Thus, these findings imply that there were not too many who may have the developed the competencies required in celestial navigation since the calculations are difficult. Though this may just be one of the reasons for not using celestial navigation enough, initiating the use of celestial navigation may be hampered in most of the mariners due to their perceived lack of competency in doing the proper calculations. This conclusion is further strengthened by the findings that majority of the respondents or 34.72% desired the incorporation of more electronic navigation skills. And this was perceived to be facilitated by the use of computer programs and navigational calculators. Moreover, 37.2% of the respondents indicated the need to change the celestial navigation curriculum (Garvin, 40) perhaps to address the limitations in using the proper skills for calculations.

A critical observation is also raised to the findings that despite the instructions provided to the mariner regarding celestial navigation, only about 35.9% continue to use celestial navigation and a close proportion of the respondents or 33.3% of the respondents do not use this method. This raises an issue about the mariners' ability to follow orders. However, a perceived inability to perform celestial calculations would have discouraged the mariner to follow the instructions.

Garvin's (43) research findings also showed that 31.2% of the respondents indicated not using celestial navigation after graduation. Knowing this perhaps would have discouraged studies to learn more intently about celestial navigation. There is a likely connection between knowing that the course may require serious effort for learning as actual practice does not require them to do so. The lack of computational skills may be attributed to this attitude over the usefulness of the course in the field.

Overall, from this study, the following observations are concluded. First, students did not perceive the importance of the course in celestial navigation as this may not be used in actual practice. Second, due to this perception, the effort which may have been expended to learn the skills particularly in calculations may not be enough. This is attributed to the perceived irrelevance of the course to practice and the difficulty encountered in learning the trigonometric calculations. Third, the respondents prefer the use of electronic navigation systems more than celestial navigation. Although they regard that celestial navigations should be used because of the limitations of electronic navigation systems, still respondents prefer the GPS. Fourth, a majority of the mariners do not follow instructions on the use of the celestial navigation systems because the vessel masters do not enforce their use and that the mariners may have been discouraged to use them due to the lack of calculation skills. Fifth, calculation skills appear to be an obstacle in acquiring the appropriate skills for celestial navigation which is probably why the respondents desired for the use of computer programs which should undertake the tough aspect of the skill. The practical use of celestial navigation and the challenging level of skills required appear to contribute to the uncertainty of continuing the use of celestial navigation. However, Garvin (55) concluded the continuance of the use celestial navigation and recommended a revision of the curriculum. He justified this with the use of technology to facilitate the ease of the tedious and lengthy calculations. An appreciation of the course may be encouraged when electronic systems would be introduced into the curriculum.

VI. CONCLUSIONS

Various tools and technology have been developed to facilitate the determination of a ship's location. From the simple tools, the sextant has been a useful tool along with the tables and almanac. Effects of their use indicated limitations to the accuracy and reliability of information. However, the introduction of state-of-the-art technologies has rendered the simple tools obsolete including the use of celestial navigation. Lately, the basic knowledge and skills of celestial navigation are deemed to be important as a backup system in case of electronic navigation system failures. Technology has exhibited various limitations that require the knowledge and skills that were established centuries before.

The effects of the use of technology in celestial navigation have been implied in the study of Garvin (2010). Since celestial navigation requires extremely challenging calculations, the need to delegate this task addresses the need for the use of technology. Accuracy and reliability of information, as well as the practice of prudence during emergency situations, shall be achieved. However, since computer systems are still electronic and may be subject to system failures, power interruptions, or computer glitches, the knowledge, and skills in manual calculations cannot be set completely set aside.

VII. RECOMMENDATIONS

In view of the literature and studies found in the use of technology in celestial navigation, the following recommendations are put forth. First, basic or manual calculations appear to be the exercise of utmost prudence. Redundancy as the best policy can be exercised with the demonstration of the centuries-old knowledge and skills in calculating locations. Second, a revamp of the curriculum may be reinforced with influencing the students of the celestial navigation course about the importance and relevance of the knowledge and skills in celestial navigation especially during times of emergencies and threats. Third, technology may be a convenient solution for addressing the difficulties encountered, but a complete reliance on this still proves to be ineffective. Students of the Naval Academy should develop the calculation skills required. Fourth, vessel masters should reinforce the need to follow instructions on the use of celestial navigation. Fifth, as there were few studies on the effects of the use of technology in celestial navigation, more studies should be ventured to explore other effects which may not be covered in this paper.

WORKS CITED

[1]. Arneson, Devine Lt. Charting a new course: Celestial navigation returns to USNA. http://www.navy.mil/submit/display.asp?story_id=91555. 15 March 2017.

[2]. Athena Navy. Project pulse: Cosmogator. 2014. https://athenanavy.wordpress.com/tag/celestial-navigation/. 16 March 2017.

[3]. Brooke, Charles. The elements of natural philosophy; Or, an introduction to the study of physical sciences. London: Churchill and sons.https://books.google.com.ph/books?id=rKwLAAAAYAAJ&printsec=frontcover&source=gbs_ge_summary_r&cad=0#v=onepage&q&f=false. 14 March 2017.

[4]. Bowditch, Nathaniel. The new American practical navigator. Sixth Stereotype Edition. 1826. New York: Edmund Blunt. N.d. https://books.google.com.ph/books?id=KcVBAAAAIAAJ&printsec=frontcover&source=gbs_ge_summary_r&cad=0#v=onepage&q&f=false. 14 March 2017.

[5]. Cline, Duane. Navigation: The cross staff. Rootsweb. 1999. http://www.rootsweb.ancestry.com/~mosmd/crstaff.htm. 14 March 2017.

[6]. Encyclopedia Britannica. Celestial Navigation. 20 July 1998. https://www.britannica.com/technology/celestial-navigation. 13 March 2017.

[7]. Encyclopedia Britannica. Navigation technology. 1 February 2012. https://www.britannica.com/technology/navigation-technology. 13 March 2017.

[8]. Encyclopedia Britannica. Sextant instrument. 1999. https://www.britannica.com/technology/sextant-instrument. 14 March 2017.

[9]. Garber, Megan. 8 tools we used to navigate the world around us before GPS and smartphones. Citylab. 15 April 2013. http://www.citylab.com/tech/2013/04/7-examples-how-we-used-navigate-world-around-us/5286/. 14 March 2017.

[10]. Garvin, Michael. Future of celestial navigation and the ocean going military navigator. Old Dominion University Digital Commons. 2010. http://digitalcommons.odu.edu/ots_masters_projects. 15 March 2017.

[11]. Garcia, Gustavo. Nautical astrolabes. Nautical Archives in Castro and Custer's Edge of Empire. 2008. http://nautarch.tamu.edu/shiplab/00-pdf/Castro%20and%20Custer%202008%20-%20Book%20-%20Edge%20of%20Empire.pdf#page=249. 15 March 2017.
[12]. GPS. Loran-C infrastructure & E-Loran. 2016. http://www.gps.gov/policy/legislation/loran-c/. 14 March 2017.
[13]. Hall, Basil. 'Chapter XIV: Doubling the cape'. The Lieutenant and Commander. London: Bell and Daldy. Project Guttenberg. 1862. http://www.gutenberg.org/files/17032/17032-h/17032-h.htm. 14 March 2017.
[14]. Kaplan, George. New technology for celestial navigation. Proceedings, Nautical Almanac Office Sesquicentennial Symposium. U. S. Naval Observatory, March 3-4, 1999. http://gkaplan.us/content/NewTech.html. 13 March 2017.
[15]. May, William Edward, *A History of Marine Navigation*, G. T. Foulis & Co. Ltd., Henley-on-Thames, Oxfordshire, 1973.
[16]. Morrison, James. The astrolabe: an instrument with a past and a future. Astrolabes. http://www.astrolabes.org/. 13 March 2017.
[17]. MSI. Chapter 16: Instruments for celestial navigation. N.d. http://msi.nga.mil/MSISiteContent/StaticFiles/NAV_PUBS/APN/Chapt-16.pdf. 14 March 2017.
[18]. Navigation Technology. Celestial navigation: Navy resurrects ancient craft to thwart hackers. 2017. http://www.naval-technology.com/features/featurecelestial-navigation-ancient-craft-reinstated-as-cyber-warfare-looms-large-4809513/. 16 March 2017.
[19]. Peterson, Andrea. 'Why Naval Academy students are learning to sail by the stars for the first time in a decade'. The Washington Post. 17 February 2016. https://www.washingtonpost.com/news/the-switch/wp/2016/02/17/why-naval-academy-students-are-learning-to-sail-by-the-stars-for-the-first-time-in-a-decade/?utm_term=.d5ae266cd220. 13 March 2017.
[20]. Prudente, Tim. 'Seeing stars, again: Naval Academy reinstates celestial navigation. Capital Gazette. 12 October 2015. http://www.capitalgazette.com/news/ph-ac-cn-celestial-navigation-1014-20151009-story.html. 13 March 2017. Proc, Jerry. OMEGA. May 2012. http://www.jproc.ca/hyperbolic/omega.html. 13 March 2017.
[21]. Strongman, Luke. "When earth and sky almost meet": The conflict between traditional knowledge and modernity in Polynesian navigation. Journal of World Anthropology: Occasional Papers. Vol. III. Number 2. http://wings.buffalo.edu/research/anthrogis/oldsite/JWA/V3N2/Strongman-art.pdf. 15 March 2017.
[22]. Tsou, Ming-Cheng. Genetic algorithm for solving celestial navigation fix problems. Polish Maritime Research. 3(75). 2012. Vol. 19. 53-59. Doi: 10.2478/v10012-012-0031-5.
[23]. U.S. Air Force. AFPAM 11-216. 1 March 2001. http://www.docucu-archive.com/AFPAM-11-216.pdf. 13 March 2017.
[24]. US Naval Observatory. Data services. 2007. http://aa.usno.navy.mil/data/index.php. 14 March 2017.
[25]. US Naval Observatory. Nautical Almanac History. 2008. http://aa.usno.navy.mil/publications/docs/na_history.php. 14 March 2017.
[26]. USNO and SPAWARSYSCEN SD. Celestial augmentation of inertial navigation systems: A robust navigation alternative. N.d. http://fer3.com/arc/img/123591.n104.pdf. 17 March 2017.

References for figures

[27]. Figure 1. Ptolemy using a quadrant. Http://www.er.uqam.ca/nobel/r14310/Ptolemy/Zilleti.html. 17 March 2017.
[28]. Figure 2. Mariner's astrolabe. Renaissancereformation.pbworks.com