Satellite Navigation Systems, As The Development Of Digitalization Of The Marine Corridor

Igor Vorokhobin †, Igor Burmaka ††, Oleksandr Ivanov†††,
Sergiy Perepechayev †††, Ivan Naboka †††, Maksym Kulakov††††

† Director of the Educational and Scientific Institute of Navigation, National University «Odessa Maritime Academy», Ukraine
†† Head of Ships' handling department, National University «Odessa Maritime Academy», Ukraine
†††Department of Navigation and Handling Ship of the Azov Maritime Institute of the National University "Odessa Maritime Academy", Ukraine
†††† Department of Ships' handling, National University «Odessa Maritime Academy», Ukraine

Summary
In the article, an analysis of the factors was carried out, which injected into the efficiency of the function of navigation systems in the minds of unimportance. Carrying out analyzes allowing for the visibility of relevant direct adjustments to the effectiveness of the function Inertial navigation systems in the minds of non-value. The designation of the navigation system was assigned to a complex of navigation systems on ships processing of the vector of navigation parameters, so that they can be victorious in the control systems of the ship's collapse, and the safety of floating is safe.
Key words:
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1. Introduction

Today, there are several navigation systems in the world that use artificial earth satellites, but there are only two that offer a truly global positioning service almost anywhere on our planet: the Russian GLONASS and the American NAVSTAR. It is to them that the popular abbreviation GPS is usually referred to.
Let's take a look at them from the point of view of an ordinary person who is not experienced in the intricacies of technology, but who has the desire (and ability) to apply the practical benefits of this technology in everyday life. Let's be honest: most citizens imagine GPS solely for portable receivers or car navigation systems. As a result, the average consumer has developed an attitude towards household GPS receivers as fun for wealthy people, or as a specific hobby.
This is partly due to the lack of popularization of GPS technology in our country. If the scientific side of the issue is covered at the proper level, in collections of scientific papers, then the presentation of information that is interesting and understandable to the mass consumer is insufficient.
For centuries, travelers have needed methods to determine their location on land and at sea. On land, it was possible with satisfactory accuracy on the basis of the terrain, using a compass, a map and marking the path traveled. The more detailed the map, the more accurately you can determine your position on the ground. In most cases, a tourist or hunter only needs to know how to get to the outskirts of a village or to a federal road. In more detail, he is guided by visual signs and at this level he absolutely does not need an exact knowledge of geodetic coordinates.
But as soon as the situation is slightly complicated, the need for precise coordinates becomes obvious. For example, in search and rescue operations, a priori knowledge of coordinates can significantly reduce the search time and save the lives of victims. Many well-equipped groups and individual travelers carry emergency beacons with them. The coordinates of some radio beacons are calculated by bearing them from satellites. Unfortunately, the accuracy of this method in many real situations is not great enough. In case of danger, GPS beacons of a new type automatically transmit their coordinates to the satellite. But in order to automatically transfer coordinates, they must first be automatically determined. Therefore, such a beacon contains a portable GPS receiver. Obviously, this is no longer an expensive toy, but an effective means of salvation.
Further, the search group can move in search, focusing exclusively on the map. Any map, being a conditional image of real terrain, firstly, must be precisely tied to the "latitude / longitude" coordinate system. Secondly, any map has certain errors in the image and snapping. The search group may simply not have a sufficiently accurate map of the terrain (this is not at all uncommon even now, especially in mountainous regions) and the real search area, when all the errors are superimposed, may "blur" for several kilometers. Pilots of military aircraft carry emergency beacons with automatic positioning. For example, the US Air Force press service has repeatedly proudly emphasized that in order to rescue pilots who ejected during hostilities, search teams needed just as long

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to locate the pilots as needed to get to a specific point.
Map snapping can be performed using traditional methods, using goniometric methods, which requires an accurate clock and a device that measures the position of the Sun in the sky at a given time. This method requires rather bulky equipment, painstaking work, special skills and gives an accuracy that is insufficient for many modern applications. Now, for geodetic purposes, there is special equipment based on differential GPS subsystems, which allows positioning control points with an accuracy of a fraction of a centimeter. Moreover, not only coordinates on the earth's surface (longitude / latitude) are automatically measured, but also the height above sea level.
Geodetic equipment, of course, does not belong to personal household appliances, but, one way or another, it has to do with us. Sooner or later, most of us will either go on a road that has practically no vertical deviations of the road, or use a high-precision map, or call an emergency service on a country road by a mobile phone with built-in GPS and be sure that they will find him there, and as quickly as possible.
If on land GPS is really perceived as an additional device, then on the high seas a satellite positioning system is almost indispensable. However, do not forget about the cases when the satellite navigation system failed during a storm and the navigator was forced, like many centuries ago, to plot the course in traditional ways[1-5].
Those who have ever used or seen a navigation system for motorists will probably agree that the navigation system itself, capable of showing a moving red dot on the map, is not so valuable for the average car enthusiast. A good car navigation system is a developed information system, in which the binding of an object to coordinates plays an almost auxiliary role. As a rule, it is more important for a car enthusiast to know the distance to a gas station, hotel, etc., rather than the latitude and longitude of his location. Therefore, modern car navigators use CDs, which, in addition to a set of maps, contain a variety of information of reference and advertising properties, up to photographs of the appearance of buildings, in order to facilitate orientation in an unfamiliar city for a motorist. This service is abbreviated as IIS - Integrated Information System. Yes, while integrated vehicle GPS + IIS systems are quite expensive, typically between $ 1200 and $ 3000. But such is the fate of all new products, there is no doubt about the upcoming price cuts and increased availability.
From the point of view of the mass consumer, the satellite positioning system has made a relatively “quiet” invasion of our daily lives. The results of this invasion are far from being as obvious and understandable as, for example, in the case of the invention and spread of telephone communications, television or the Internet. Nevertheless, the abbreviation GPS is increasingly heard in everyday life, and the corresponding equipment is finally in a sufficient range and at an affordable price in our country.
It is necessary to clarify the basic terminology from the outset. Let's start with the fact that, unfortunately, the United States has become the de facto "standard-setter" in satellite positioning, and especially in its consumer segment. This is a widespread consumer equipment that is associated around the world, primarily with the US-owned navigation system NAVSTAR. The reason is, rather, not in the national scientific potential, but in the fact that the United States was able to regularly invest hundreds of millions of dollars in its program, precisely at the time when the Soviet Union was going through the most difficult times of stagnation and subsequent collapse. After all, satellite positioning is, first of all, a space program, which entails a lot of related research and development, requiring huge capital investments. Historically, having launched the first satellite and being a recognized world leader in space exploration, our country is still experiencing problems with building its own satellite navigation system.
It would be wrong, in my opinion, to assume that only civilian needs were the impetus for the creation of GPS. Global positioning systems in the United States were created primarily for military purposes. In 1960 ... 1970. The arms race was in full swing and the military was in dire need of a high-precision positioning system that would operate anywhere in the world and be available around the clock to any military facility. The military doctrines of developed countries have undergone significant changes by this time. Nuclear weapons have appeared that have tremendous destructive power, effective carriers have been created that can deliver them to any region. It became obvious that with the use of such powerful weapons, the war simply could not be long, and the winner would be the one who was the first to deliver remote strikes against the enemy's infrastructure with maximum accuracy. The first requirement of the military was to create a system for the precise guidance of missiles and bombers to the target. In addition, the Navy was in dire need of an efficient and reliable navigation system for missile-carrying submarines. On the one hand, it is necessary to ensure the positioning of the submarine itself, preferably without frequent surfacing, and on the other hand, to organize the targeting of the ballistic missiles on board.
The next, after the military, the largest consumer of precision positioning services are government mapping services.

2. Theoretical Consideration

First, the true globality of the navigation service can only be ensured by the use of satellites, since any other system will certainly have a local character. Ground stations can be placed only on the territory of their own country or friendly countries, the sea spaces in this case cannot be fully covered at all. Secondly, the use of stations located on the earth's surface does not allow determining the height of an object with the required accuracy. In addition, the use of satellites emitting ultra-high frequency signals makes the user equipment truly mobile. Mobility is also increased due to the fact that the maximum possible functional load is placed on the satellites and ground control stations, and the mobile receiver only has to perform the final processing of the previously prepared information.

Each satellite that is part of a GPS emits a radio signal of a certain kind. Any user GPS device, civil or military, is primarily a receiver of these radio signals (therefore, the not entirely correct phrase "GPS receiver" arose). But it is not enough to receive signals from satellites, it is necessary to measure their parameters, extract the information embedded in them and make rather complex calculations. The information received most often needs to be displayed in a form that is understandable to a person. The device that does all these operations is called the GPS user terminal (or indicator receiver), whereas a simple GPS receiver is usually just a module of a more complex device or complex system. But traditionally, in everyday life, mobile GPS terminals are simply called receivers.

As often happens, needs stimulate the emergence of new opportunities, and new opportunities, in turn, give rise to new ideas and needs. So, for example, with the advent of portable GPS receivers, the idea arose of creating a fundamentally new car security system. Such a system is able to accurately track the coordinates of the vehicle and transmit them to the control post using conventional cellular communications. It became possible to fundamentally rebuild the train traffic control system by placing GPS receivers on them. The new system is able not only to accurately track and optimize train traffic, but also to automatically activate the emergency braking mode in the event of a dangerous approach of trains.

Moreover, at present, GPS is even used to solve such an extremely critical task as the automatic introduction of aircraft to the landing glide path and further to the point of contact with the runway. Of course, in this case, especially stringent requirements are imposed on the system and special functional additions are applied. For example, the complementary component could be a precisely positioned terrestrial transmitter that simulates a satellite signal (pseudolith).

The absence of unreasonable bureaucratic barriers and the affordability of household GPS receivers have made satellite positioning equipment an indispensable element of equipping tourists, hunters, fishermen - in other words, everyone who is forced to travel far from home.

Modern car manufacturers build GPS equipment in some car models as standard equipment. So far, these are only expensive models, but there is a tendency to complete with GPS terminals and models of the middle price range. There is no doubt that sooner or later a GPS receiver will become a must-have component of any vehicle.

These facts prove once again that in the near future satellite navigation systems will increasingly affect the quality of our daily life, and information about their structure and capabilities is of great cognitive value for people interested in the achievements of modern science.

Satellite navigation systems and their applications are one of the fastest growing industries in the world economy. If by 2018 the total turnover of its products amounted to approximately 1 billion euros, then by 2015 it will exceed 8 billion euros.

Satellite navigation equipment has found wide application and is considered standard for ships and aircraft, and not even of the highest class, spacecraft. It has become a common tool in land management, monitoring, surveying and surveying.

The release of relatively inexpensive consumer equipment led to the beginning of its entry into our everyday life, sports, tourism and travel.

The use of satellite equipment for car navigation has become strikingly widespread. By 2019, the share of the total cost of such devices in the European market, according to Thales1, was 73%, while the shares of aviation and the navy did not exceed 5 and 4%, respectively. However, we are on the verge of even more powerful changes due to the emerging trend towards the integration of mobile phones (MT) and receivers of satellite radio navigation systems (SRNS). The first samples of the combined GSM + GPS equipment from Benefon were released on our market. According to Thales' forecast, by 2005, GPS-integrated “tubes” will account for 73% of the European market for SRNS products, automotive receivers - 23%, and the shares of aviation and maritime assets will not exceed 1% each.

The combination of satellite navigation and mobile telecommunication technologies is determined by the desire to provide the user with accurate knowledge of the place for his access to information sources and the effective operation of the rescue service. Thus, satellite receivers began to invade the field of communications, data processing and transmission, information technology and the Internet.

At the same time, the satellite radio navigation systems themselves do not stand still. GPS is under development and modernization. Complementary wide-area differential subsystems - the North American WAAS and the European EGNOS - are under testing, a similar Japanese MSAS subsystem is under construction, and the network of marine and geodetic differential subsystems is expanding. New, more advanced models of user equipment are being developed and appear on the market, and methods of its use are being improved.

All these factors determine and support the persistent interest in satellite navigation issues and its applications on the part of many readers, which is not satisfied with the available literature.
After the invention of radio and the development of directional antenna designs, quite obvious attempts were made to use radio beacons for navigation purposes that work outside of optical visibility. In addition to maritime navigation, radio beacons have become widely used (and are still used) in aviation for laying and correcting the course of aircraft. As a rule, they operate in the medium wave range, and a combined loop antenna with a narrow radiation pattern is used to receive the signal. There are VHF beacons. Distinguish between long-range and short-range aircraft radio beacons. Radio beacons allow you to correct the readings of the onboard magnetic compass and partially replace or duplicate it. The accuracy of the on-board radio compass allows pilots to reliably reach such a distance to the airfield at which further visual orientation in space is possible, for example, in the terrain (small aircraft) or runway lights.
Analyzing the operation of radio navigation systems based on radio beacons, one can find that traditional radio compasses, solving the heading problem with acceptable accuracy, do not allow solving the problem of precise positioning on the ground, i.e. determining the longitude and latitude of the object[7].
Suppose we have two coastal transmitters, A and B, and a receiver located on the ship, O. The transmitters emit a signal uniformly in all directions. The antenna of the ship's receiver is directional, i.e. when it is turned towards the transmitter in a certain way, the amplitude of the received signal increases many times over. Theoretically, if we ideally accurately determined the directions to the transmitters with previously known coordinates, then we accordingly accurately determined our position at the only possible intersection of azimuths at point O.
The distance to the transmitters is many times the wavelength, which is why we consider transmitters as point emitters.
The problem is that there are no antennas with an ideal radiation pattern, and the sharper the directivity of the antenna, the more complex its design. In addition, if we want the positioning system to operate outside of optical visibility, we must use radio waves long enough to bend around the horizon. But the longer the wavelength, the larger the physical dimensions an ideal directional antenna should have. Therefore, the accuracy of the directional antenna is limited by its reasonable design dimensions.
The error in determining the azimuth to the radio beacon, presented in the form of a certain angle φ, can be conditionally projected by means of simple geometric transformations into the opposite angle φ 'with the top of the radio beacon position [2].
Obviously, taking into account the azimuth error, instead of the exact coordinates, we get a certain area of probable location.
At distances to radio beacons in the hundreds of kilometers, the azimuth measurement errors in fractions of a degree are projected into the position measurement errors in the hundreds of meters. On long air routes, the aircraft positioning error reaches several kilometers in terms of the lateral deviation from the route.
In stationary conditions, it is possible to significantly narrow the area of probable location, taking as a basis such an antenna angle, which is the average between the two extreme reliable positions. However, in practice, in conditions of an unstable moving object, such as a small vessel, it is extremely difficult to choose the right directions, since it requires gyroscopy of the entire receiving antenna unit. Such mechanical systems are very expensive and unreliable.
In addition, in the case of two transmitters A and B, if they are located in line with the receiving antenna, there is an absolute impossibility of determining the position. The presence of a third radio transmitter eliminates the ambiguity problem, but only slightly improves the positioning accuracy.
Therefore, in order to successfully solve the positioning problem, it is necessary to measure the ranges, i.e. distance between receiver and transmitters. Knowing only the ranges of up to three transmitters located in the same plane with the receiver, it is possible to unambiguously solve the positioning problem[5].
The coordinates of the object (point O) are the coordinates of the point of intersection of imaginary circles with radii R1, R2 and R3 equal to the distances. The third transmitter is necessary to eliminate possible ambiguity arising from the intersection of two circles (points O and O '). Obviously, in the case of measuring ranges, the directivity of the receiving antenna does not affect the positioning accuracy. But the accuracy of the synchronization of the time scales of the transmitters and the receiver and the magnitude of the error that occurs when measuring the signal propagation time are of decisive importance.
The advent of extremely accurate atomic clocks in the 1960s made it possible to significantly reduce the errors of the rangefinder method, to a level sufficient for its widespread use in practice.
The practical implementation of the rangefinder method in the United States is the LORAN (Long Range Aid to Navigation) marine navigation system, which is extremely important in the history of GPS development, since it was the first to use the determination of the signal transit time from the transmitter to the receiver, which received further development in satellite navigation systems. The value of the propagation speed

of a radio signal has long been known to science, therefore, having measured the propagation time of a radio signal with sufficient accuracy, you can easily calculate the exact distance to the transmitter. The transmitter emits a signal continuously, and the signal propagation time is calculated from the phase incursion over the time the radio waves travel the distance to the receiver. Since the relative phase incursion is directly proportional to the signal transit time, the distance to the transmitter is calculated from the phase difference between the receiver's internal reference signal and the received signal.

As has happened and is happening with many high technologies, at first GPS was developed as a purely military system, and with money allocated from the US state budget for the needs of the Department of Defense. The military needed, on the one hand, means of targeting high-precision long-range weapons, and, on the other hand, a universal navigation system available for mass use in the army. The obvious solution was to combine these two tasks into one - to create a precise positioning system. Beginning in the 1960s, the US Department of Defense began to develop the idea of creating a global, all-weather, continuously available, highly accurate navigation and positioning system[2].

In the case of GPS, the US Department of Defense has tried to show a rare foresight in terms of subsequent money savings. It was obvious that a system with similar characteristics has broad prospects for civilian use. Therefore, from the very beginning, the developers were required to make the terminal (user) equipment available to a wide variety of users, but on condition that the military can, at will and at any time, limit its functionality, up to complete blocking. It was also implied that the US Department of Defense would manage the distribution of user equipment, partially offsetting its costs. It is known that in the end it turned out not quite like this: many independent commercial organizations are engaged in the development, production and sale of user equipment, and the real amount of costs many times exceeded the initial calculations. But, in any case, the United States was right. Figuratively speaking, almost the entire civilized world has swallowed a giant bait on a hook that can always be hooked. Here's an effective example: if the US government completely closes access to the GPS service for civilian users, it will be partially difficult, and in some cases completely paralyzed, the work of mobile networks around the world. The fact is that to synchronize communication networks it is cheaper and easiest to use the exact time signal from GPS or GLONASS satellites, but in reality, the equipment of the GPS NAVSTAR standard is much more widespread in the world. Understanding this problem has led to the fact that now an increasing number of user receivers have the ability to work in two systems.

With the basic requirements for the system identified, the US Navy and Air Force began developing a concept for the use of radio signals emitted from satellites for navigation and positioning purposes. Undoubtedly, the impetus for this path of development was the launch of the first artificial satellite by the Soviet Union in 1957. The United States closely followed the flight of Soviet satellites, receiving the signal of the onboard transmitter at ground points with previously known coordinates. The parameters of the signal transmission through the thickness of the earth's atmosphere and the Doppler frequency shift arising when the satellite moves in orbit were studied. Research by APL (Applied Physics Laboratory, Applied Physics Laboratory) has shown that the Doppler shift can be used to calculate the full orbit of a satellite. Dr. Frank T. McClure of APL pointed out that conversely, if the full orbit of the satellite is known, then the Doppler shift can be used to calculate the exact position of the satellite in orbit. Interest in the inverse problem arose: the calculation of the coordinates of the receiver based on the signals received from the satellite.

The Navy funded two precursor programs to GPS: Transit, Timation. The Transit system was the first operational satellite navigation system. Developed in 1964 at the Johns Hopkins Laboratory of Applied Physics under the direction of Dr. Richard Kershner, the Transit system consisted of 7 low-orbit satellites that emitted very stable radio signals. Several ground tracking stations monitored and adjusted the orbit parameters. Transit users determined their coordinates on the earth's surface by measuring the Doppler frequency shift from each satellite.

Originally developed by the Navy to control Polaris ballistic missile submarines and other military installations on the ocean surface, the Transit system became available to civilian users in 1967[3].

She was very quickly adapted for the navigation of large commercial ships and small private boats and yachts. Moreover, the number of civilian users quickly exceeded the number of the military. Despite the fact that the Transit system provided the basic needs for navigation of ships, it had many disadvantages: low speed, the need for long-term observation of satellites, the ability to position only stationary or slowly moving objects, determination of only two dimensional coordinates, lack of continuous availability (time when none of the satellites was visible, it was measured for hours), the need for the user to make adjustments for moving objects on his own - all this made it impossible to use the system in aviation and other fast moving objects. The inability to selectively restrict access to the system played an important role. Nevertheless, the new technologies incorporated in the Transit were very important for the subsequent development of GPS. For example, GPS uses a satellite prediction algorithm pioneered for Transit [1].

The second predecessor to GPS, Timation, was developed at the NRL (Naval Research Laboratory) under the direction of Roger Easton. The research program started in 1964 and included the launch of two artificial satellites carrying the previously developed ultra-stable clocks, the transmission of precise time signals from the satellite, and the determination of two-dimensional coordinates of the receiver. The main idea was to use synchronized transmitters emitting a coded signal. By measuring the propagation delay of a signal from satellites with known coordinates, it is possible to calculate the distance to the satellites and based on this, the coordinates of the receiver. Thus, the basic principle of GPS operation was laid and experimentally tested.

The first satellite, the Timation system, launched in 1967, carried an ultra-stable quartz clock on board; subsequent models used the atomic frequency standard (rubidium and cesium). The atomic clock made it possible to significantly improve the prediction of satellite orbits and significantly increase the interval between adjustments of the satellite clock from the ground control station. These advanced developments in the space time standard were a major contribution to the development of GPS. In fact, the last two satellites of the Timation system were working prototypes of GPS satellites [1-3].

In the meantime, the US Air Force was working on a similar technology program, later called the 621B System. It presented the possibility of 3D (latitude, longitude and altitude) navigation with continuous access. In 1972, the work of a system was demonstrated using a new method of separating satellite signals - code division based on a pseudo-random, noise-like signal. In this embodiment, all satellites emit on a single carrier frequency, which is modulated by a very long pseudo-random code (PSK), individual for each satellite. The spectrum of such a signal is very similar to the spectrum of random noise with a Gaussian distribution, which is why the signal is called noise-like[4].

The use of a pseudo-random code can significantly increase the noise immunity and transmit information about the position of satellites (ephemeris) and time stamps in the signal. Also, when using pseudo-random coding, the access restriction problem is easily solved. In the simplest case, codes can be either open for public use or secret. Only open codes are available to civilian users, so it is enough to introduce deliberate errors in the information transmitted by open codes on a command from the ground control point, as only military equipment remains operational, and civilian receivers will cease to function with acceptable accuracy.

To test the PSK technology, the US Air Force conducted a series of experiments at the White Desert Proving Ground in New Mexico. To simulate satellites, transmitters placed on balloons and airplanes were used. The experimental equipment positioned the aircraft to within hundredths of a mile. At the same time, the concept of a global system of 16 satellites in geostationary orbits was formulated, whose projections onto the earth's surface formed four oval clusters elongated 30 degrees north and south of the equator. This particular geometry allowed for a consistent development of the system, since four satellites were sufficient to demonstrate real performance. Consequently, one full cluster of four satellites provided 24-hour coverage for a specific geographic region (eg North or South America) [4-7].

However, until 1973 there was no discernible shift in the development of the full-scale 621B System. Part of the reason for this was the support from the Air Force for additional satellite navigation developments based on several parallel initiatives from various organizations. Since the 1960s, the US Navy, US Air Force, and ground forces have independently worked on a radio navigation system that provides all-weather 24-hour coverage with an accuracy sufficient for military use by their respective services. The Applied Physics Laboratory developed the hardware for the Transit system and was about to improve the system, while the Naval Research Laboratory was vigorously expanding the Timation system; the ground forces offered to use their own system called SECOR (Sequential Correlation of Range). The resulting situation began to worry the US Department of Defense, as various strategies for building the system were tested in practice and it was time to build a single concept. To coordinate the efforts of all research groups developing various navigation systems, the US Department of Defense established a tripartite joint committee called NAVSEG (Navigation Satellite Executive Group). Over the next few years, the committee finally decided what the satellite navigation system should be - the number of satellites, orbital heights, signal codes, modulation method - and how much it would cost.

Finally, in April 1973, the Air Force was approved as the lead developer, integrating various concepts for building satellite navigation systems into a single comprehensive military system known as DNSS (Defense Navigation Satellite System). The new system was to be developed at the Air Force Joint Development Center in partnership with all interested military services. Air Force Colonel Brad Parkinson, Program Director of the Joint Center, led the interaction between the various services to develop the DNSS concept.

By September 1973, a compromise system had been created that absorbed all the best options from the previous programs of the Air Force and the Navy. The signal structure and frequencies were borrowed from the "System 621B". The orbits of the satellites were based on the structure proposed for the Timation system, but with a higher altitude, providing a 12-hour orbital period instead of an 8-hour one. Both systems involved the use of atomic clocks on satellites, but only the Air Force put the idea to the test. The system, built on the formulated concept, is now known as the global positioning system NAVSTAR. In December 1973, the US Department of Defense approved and financed the first phase of the development of NAVSTAR GPS (the work plan provided for three phases).

Conclusions

In the article, from the analysis of the factors influencing. The efficiency of marine navigation systems has shown that the main ones that affect the efficiency of navigation systems are errors in measuring accelerometer acceleration and errors in their angular orientation and drift of the inertial gyroscope relative to the axis of the world caused by imperfect gyroscopes. A qualitative analysis of the modern maritime navigation system used in the world.

It is determined that promising areas of further research may be: the creation of methods to increase the battery life of inertial navigation systems without losing the accuracy of determining the main navigation elements; development of methods for automatic adjustment of inertial systems.

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