

# Navigation instruments and equipment

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Preddiplomski sveučilišni studij Nautike i tehnologije pomorskog prometa (jednopedmetni - redoviti)



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Navigation Instruments and Equipment

Završni rad

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Zadar, 2016.



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Sadržaj mojega rada u potpunosti odgovara sadržaju obranjenoga i nakon obrane uređenoga rada.

Zadar, 14. srpnja 2016.

# Contents

<a href="#">1. Introduction</a>	5
<a href="#">2. History</a>	6
<a href="#">3. Navigating Bridge</a>	9
<a href="#">4. Marine Radar</a>	9
<a href="#">4.1 Principles of range and bearing measurement</a>	10
<a href="#">4.2 The Echo Principle</a>	10
<a href="#">5. Automatic radar plotting aid (ARPA)</a>	11
<a href="#">5.1 Criteria of tracking</a>	12
<a href="#">5.2 Acquisition and tracking</a>	12
<a href="#">6. The Global Maritime Distress and Safety System (GMDSS)</a>	12
<a href="#">6.1 The basic concept of GMDSS</a>	13
<a href="#">7. The Electronic Chart Display and Information System (ECDIS)</a>	15
<a href="#">7.1. Basic concept of ECDIS</a>	15
<a href="#">7.2. Definitions</a>	16
<a href="#">8. Global Positioning System (GPS)</a>	19
<a href="#">8.1. Basic concept of GPS</a>	19
<a href="#">9. Conclusion</a>	21
<a href="#">10. Glossary</a>	22
<a href="#">11. References :</a>	23
<a href="#">11.1. Pictures</a>	24

## **1. Introduction**

Aids to navigation are implanted in every segment of modern navigation. The history proceeding it is one of the richest and most interesting. With navigational instruments and equipment, navigators increase accuracy of data that is crucial when underway. Changes and improvements are usual and constant, with aim to make the voyage easier, safer, and more pleasant not only for the crew but also for passangers.

Not all instruments are up to date and dependent on electric power. The usage of some of the oldest instruments is still important, and every mariner has to be able to obtain informations from them. However, nowadays, navigators rely more on modern equipment than ever. Without research and development of aids to navigation , modern sailing would be a lot different.

Many books have been written about navigational equipment explaining their usage, their characteristics and the importance of each one. Reviewing the literature gives a reader an insight of each component, furthermore, it helps understanding them.

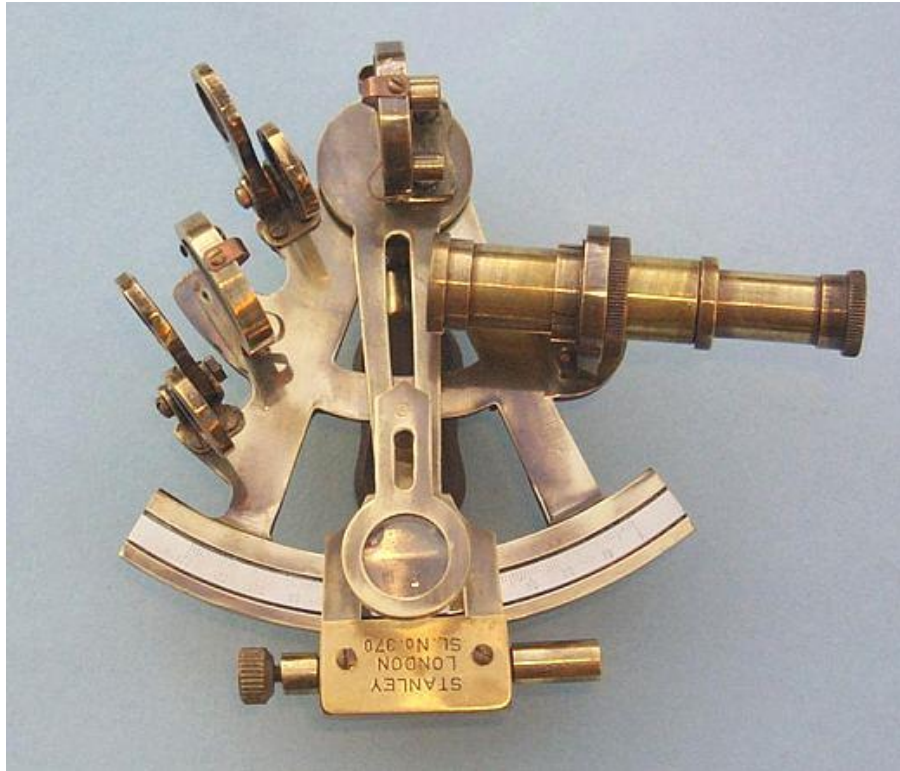
## 2. History

Navigation is in fact the art of directing vessels through water and establishment of its positions and courses by means of astronomy, geometry or special navigational instruments. One of the oldest and earliest navigational tool used was mariner's compass. It was used when the Sun was not visible. The compass was an early form of magnetic compass. It was often innacurate and incosistent because of magnetic variation, which was not understood at that time. Nautical charts were introduced during the mid-thirteenth century. Mariners had realised it would be helpful if they kept detailed record of their voyages. There were no latitude or longitude labeled on chart, but there was a compass rose which indicated the direction.



Picture 1. Compass and map

Means of determing the angle between the Sun, moon, stars and the horizon were introduced in 1730. The device was invented by an English mathematican John Hadley and an American inventor Thomas Godfrey. The name of that device is sextant.



Picture 2. Sextant

The chip log was invented and used as a crude speedometer in the sixteenth century. The chip log was let out over the stern when ship was underway. It contained a line with regular interval knots. A mariner would count the number of knots that went out over precise time period and the ship's speed could then be calculated. The chronometer was invented by a British clockmaker John Harrison in 1764. It was made for precise and accurate determination of longitude by means of celestial navigation.





Picture 3. Chronometer

The gyroscopic compass was introduced in 1097. The gyro compass is unaffected by ship's or Earth's magnetic field and always points to true north. In 1935 the Radar was introduced. Radar stands for „Radio detection and ranging“. Its primary purpose is locating objects beyond range of vision. The Loran was developed during 1940s. This navigation system stands for Long Range Navigation. It uses pulsed radio transmission from so called „master“ and „slave“ stations to determine a ship's position. Loran is accurate but its coverage is limited. On most vessels Loran was replaced in the late twentieth century by global positioning system, known as GPS. Its principle of work is similar to Loran but it uses signals from a satellite.

### 3. Navigating Bridge

Room from which the ship is operated is called a nautical or a navigating bridge. The navigating bridge has its control panel, from which sailing is carried out. Moreover crucial controlling points are found there. Various alarm systems, the navigating equipment, instruments and light switches. However with all important equipment, navigator's best instrument are his eyes and his capability of understanding the situations that he can meet.



Picture 4. Navigating bridge – Catamaran Paula

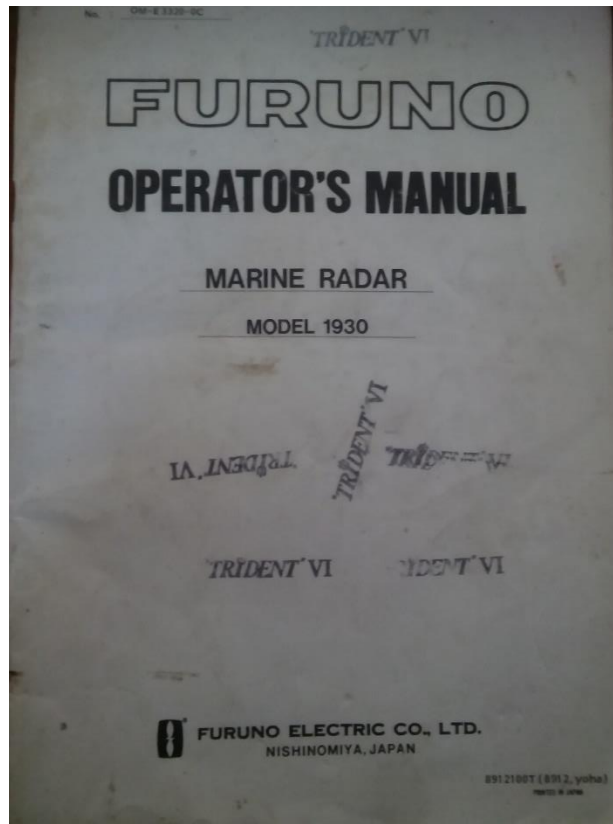
Each and every machinery onboard must have its own manual , explaining how to operate and has detailed descriptions of how to use it. Manuals change in accordance with new editions. Manuals contain descriptions of:

- Warnings
- First Aid in case of electric shock
- Method of Artificial respiration
- Radiation Hazard
- Contents
- Specifications

- Principle of operation
- Installation
- Operational Overview
- Application
- Maintenance
- Troubleshooting
- Schematic diagrams
- Outline drawings

Example of warning :

„The operation of this equipment involves the use of high voltage, which endangers human life. Although the design of the equipment has been made in due consideration of measures to insure the operator's safety, adequate precaution must be exercised when reaching inside the equipment for the purpose of maintenance and service. Do not change a component or inspect the equipment with the voltage applied. A residual charge may exist in some capacitors with the equipment turned off. Always short all supply lines to the chassis with an insulated screwdriver or a similar tool prior to touching the circuit.“[1]



Picture 5. Operator's Manual for Marine Radar – Catamaran Olea

## 4. Marine Radar

„Radar on Merchant Ships was initially installed for commercial purposes. The early customers were ferries, which could then maintain better schedules in fog, and large fishing vessels. Radar was treated with great suspicion by the mariners of the day and was usually the preserve of the master, who locked it so that it could only be used when he was on the bridge. Ports also started using radar for the commercial purposes of berthing ships in fog; one example is the Port of Liverpool, in 1948.“ [3]

„Radar forms an important component of the navigational equipment fitted on virtually all vessels apart from the very smallest. Its display of critical information is easily assimilated by a trained user and has acted as a focus for the presentation of other navigational data, giving it a deserved prominence on the bridge of a vessel. It is poised to retain its central electronic navigational role into the foreseeable future, equalled only in display significance by the rather more recent development, the electronic chart. Together, they will provide the basis of the major displays for marine navigation into an increasingly integrated navigational world. The word RADAR is an acronym derived from the words Radio Detection and Ranging.“ [2]



Picture 6. RADAR – Kraljica Mora

#### ***4.1 Principles of range and bearing measurement***

„Conventional marine and VTS radars generate a steady train of pulses - bursts of oscillation - of microwave power. An antenna transmits the energy in a continuously rotating beam. Any object in its path scatters the radiation reaching it. A very little returns to the radar. Object bearing is that of the antenna, range being measured by the delay before reception. The pulses have quite high power of 10kW but very short duration, 1  $\mu$ s or less. A pulse is transmitted at the speed of light, 300m/ $\mu$ s, sweeps out and strikes any scatterer on or above the sea surface lying in its path, indicated by the direct path. Some of the incident energy is absorbed within the scatterer. The remainder is scattered through a broad solid angle. The tiny part returning to the antenna forms an echo. Knowing that transmission and echo each propagate at the speed of light, the elapsed time to reception measures echo range, with uncertainty inversely proportional to the pulselength. The two-way scaling is 150 m/ $\mu$ s or 6.67  $\mu$ s/km. In radar work, time and range are often interchangeable. Each transmitter pulse is in effect 'time stamped' for measurement of echo delay.“ [3]

#### ***4.2 The Echo Principle***

„An object (normally referred to as a target) is detected by the transmission of radio energy as a pulse or otherwise, and the subsequent reception of a fraction of such energy (the echo) which is reflected by the target in the direction of the transmitter. The phenomenon is analogous to the reflection of sound waves from land formations and large buildings.

- A. The echo is never as loud as the original shout.
- B. The chance of detecting an echo depends on the loudness and duration of the shout.
- C. Short shouts are required if echoes from close targets are not to be drowned by the original shout.
- D. A sufficiently long interval between shouts is required to allow time for echoes from distant targets to return.
- E. It can be more effective to cup one's hands over the mouth when shouting and put a hand to the ear when listening for the echo.“[2]

„Targets are all objects, such as ships, of current interest to the operator. Although the Collision Regulations are written round aspect (relative bearing of target centreline) as indicated visually by navigation lights, often the radar discrimination is too coarse separately to display the individual scatterers comprising the target object and thus its aspect. Heights cannot be

determined by radar. Radar is valued for its ability to position targets in range as well as bearing, and its general independence of cooperative equipment at the target. Although good signal processing facilities do the donkey work in presenting the clearest possible display, only the operator can decide that vital question - what to do?“ [3]

## 5. Automatic Radar Plotting Aid (ARPA)

„With computers developing at an ever increasing pace, it was only a matter of time before their capabilities were harnessed to assist the mariner in resolving the continuing problem of tracing targets and analysing their movements when faced with heavy traffic. In the past, many semi-automatic devices were developed to assist in this task but only those systems which conform to the IMO Performance Standards for Automatic Radar Plotting Aid (ARPA) are rightfully entitled to be classified as ARPAs. The IMO Performance Standard for an ARPA requires that it should „... reduce the workload of observers by enabling them to automatically obtain information so that they can perform as well with multiple targets as they can be manually plotting a single target.“ [4] „New SOLAS ships carrying ARPA or reduced ARPA require an integrated input from a gyro and a speed log that measures speed through the water. In the regulations, these are known as the THD (transmitting heading device) and SDME (speed and distance measuring equipment). Without reasonably accurate data from these sources, the ARPA functions have limited value.“ [2]



Picture 7. – Automatic Radar Plotting Aid

### ***5.1 Criteria of tracking***

„A target measuring 800 m or more in the radial or circumferential direction is regarded as a landmass and not acquired or tracked. Echoes smaller than 800 m are regarded as targets to be tracked. The FURUNO ARPA ATA video processor detects targets in the midst of noise and discriminates radar echoes on the basis of their size. Target whose echo measurements are greater than those of the largest ship in range or tangential extent are usually land and are displayed only as normal radar video. All smaller ship-sized echoes which are less than this dimension are further analyzed and regarded as ships and displayed as small circles superimposed over the video echo. When a target is first displayed, it is shown as having zero true speed but develops a coursevector as more information is collected. In accordance with the International Marine Organization Automatic Radar Plotting Aid (IMO ARPA) requirements, an indication of the motion trend should be available within 20 scans of antenna and full vector accuracy within 60 scans. The FURUNO ARPAs/ATAs comply with these requirements.“ [5]

### ***5.2 Acquisition and tracking***

„A target which is hit by 5 consecutive radar pulses is detected as a radar echo. Auto acquisition is not defined in paints but in time, which should be less than 3 seconds of initial stage. Manual acquisition is done by designating a detected echo with the trackball. Automatic acquisition is done in the acquisition areas when a target is detected 5-7 times continuously depending upon the congestion. Tracking is achieved when the target is clearly distinguishable on the display for 5 consecutive or alternate paints out of 10 consecutive scans whether acquired automatically or manually. Required tracking facilities are available within 0.1-32 nm on range scales including 3, 6, 12 nm; full plotting information is available within one scan when the range scale has been changed. Targets not detected in 5 consecutive scans become “lost targets”.“ [5]

## **6. The Global Maritime Distress and Safety System (GMDSS)**

The Global Maritime Distress and Safety System (GMDSS) has been developed to provide mariners with a global communication and locating network, the elements of which are capable of being operated by an individual with minimum communication knowledge and yet enable alerting and search and rescue (SAR) services to be reliably co-ordinated.



## ***6.1 The basic concept of GMDSS***

„The basic concept of the GMDSS is that SAR authorities ashore, in addition to shipping in the immediate vicinity of a casualty, must be rapidly alerted to a distress incident so that they can assist in a co-ordinated SAR operation with the minimum of delay. This statement lead to nine defined principal communications functions.

1. Distress alerting-ship-to-shore. There must be a means of transmitting ship-to-shore distress alerts by at least two separate and independent methods, each using a different radiocommunication service.
2. Receiving distress alerts--shore-to-ship.
3. Transmitting and receiving distress alerts---ship-to-ship.
4. Transmitting and receiving SAR co-ordination communications.
5. Transmitting and receiving on-scene communications.
6. Transmitting and receiving locating signals. (Radar transponders and standard navigation radar equipment.)
7. Transmitting/receiving maritime safety information (MSI).
8. Transmitting and receiving general radiocommunications from shore-based radio networks.
9. Bridge-to-bridge two-way communications.

Every vessel, over 300 grt, which chooses to operate subject to the GMDSS regulations must be provided with the following minimum fitting of radiocommunications equipment:

- a VHF radio installation providing communications on channels 6, 13 and 16 with the facilities for DSC alerting on channel 70;
- a receiver for continuous DSC watch on channel 70;
- two radar transponders (SART) transmitting in the 9 GHz maritime band;
- a NAVTEX receiver;
- a receiver for the reception of maritime safety information transmitted by Inmarsat's Enhanced Group Call (EGC) system if on voyages in sea areas of Inmarsat coverage where NAVTEX is not provided;
- satellite EPIRB capable of being manually or automatically activated to float free;

- two (three on ships over 500 grt) waterproof VHF hand-held transceivers for on-scene communications;
- MF communications on 2182 kHz (until February 1999).

A GMDSS alert is usually initiated and acknowledged manually. Such an alert is easily initiated by using DSC on *MF/HF*, by pressing the 'red' button on an Inmarsat-A or B SES or by keyboard commands using an Inmarsat-C SES. The alert must be capable of being initiated from the position from which the vessel is normally navigated.

However, if disaster overwhelms a vessel before an alert can be initiated, a float-free satellite EPIRB is automatically released and activated. This alert is received and decoded by the polar orbiting COSPAS-SARSA T satellites with a subsequent link into the GMDSS radionet.“ [6]



Picture 8. GMDSS

## 7. The Electronic Chart Display and Information System (ECDIS)

### 7.1. Basic concept of ECDIS

„Electronic chart display and information system (ECDIS) means a navigation information system which, with adequate back-up arrangements, can be accepted as complying with the up-to-date chart required by regulation V/20 of the 1974 SOLAS Convention, by displaying selected information from a system electronic navigational chart (SENC) with positional information from navigation sensors to assist the mariner in route planning and route monitoring, and by displaying additional navigation-related information if required.“ [7]



Picture 9. ECDIS - Catamaran Olea

„The primary function of the ECDIS is to contribute to safe navigation. ECDIS, with adequate back-up arrangements, may be accepted as complying with the up-to-date charts required by regulation V/20 of the 1974 SOLAS Convention.

In addition to the general requirements for shipborne radio equipment forming part of the global maritime distress and safety system (GMDSS) and the requirements for electronic navigational aids contained in IMO resolution A.694(17), ECDIS should meet the requirements of this performance standard. ECDIS should be capable of displaying all chart information necessary for safe and efficient navigation originated by, and distributed on the authority of, government-authorised hydrographic offices. ECDIS should facilitate simple and reliable updating of the electronic navigational chart. Use of ECDIS should reduce the navigational workload as compared to use of a paper chart. It should enable the mariner to execute in a convenient and timely manner all route planning, route monitoring and positioning currently performed on paper charts. It should be capable of continuously plotting the ship's position. ECDIS should have at least the same reliability and availability of presentation as the paper chart published by government-authorised hydrographic offices.

ECDIS should provide appropriate alarms or indications with respect to the information displayed or malfunction of the equipment“ [7]

## ***7.2. Definitions***

„Electronic navigational chart (ENC) means the database, standardised as to content, structure and format, issued for use with ECDIS on the authority of government-authorised hydrographic offices. The ENC contains all the chart information necessary for safe navigation, and may contain supplementary information in addition to that contained in the paper chart (e.g. sailing directions) which may be considered necessary for safe navigation. System electronic navigational chart (SENC) means a database resulting from the transformation of the ENC by ECDIS for appropriate use, updates to the ENC by appropriate means, and other data added by the mariner. It is this database that is actually accessed by ECDIS for the display generation and other navigational functions, and is the equivalent to an up-to-date paper chart. The SENC may also contain information from other sources. Standard display means the SENC information that should be shown when a chart is first displayed on ECDIS. The level of the information it provides for route planning or route monitoring may be modified by the mariner

according to the mariner's needs. Display base means the level of SENC information which cannot be removed from the display, consisting of information which is required at all times in all geographical areas and all circumstances. It is not intended to be sufficient for safe navigation.“ [7]

ECDIS should be capable of displaying all SENC information and present display at any time by a single operator action. Latest edition of chart information from government-authorized hydrographic office should be used in ECDIS. Furthermore ECDIS should not degrade the performance of any equipment providing sensor inputs, nor should the connection of optional equipment degrade the performance of ECDIS below standard.

Moreover suitable alarm or indication of system malfunction should be provided in ECDIS. It should be possible to operate ECDIS and all equipment necessary for its normal functioning when supplied by an emergency source of electrical power. Accuracy of calculations performed by ECDIS should be independent of the characteristics of the output device and should be consistent with the SENC accuracy. Bearing and distance drawn on the display should have an accuracy no less than that afforded by the resolution of display.

## **8. Global Positioning System (GPS)**

„The Global Positioning System is a space-based navigation system that provides location and time information in all weather conditions, anywhere on or near the Earth where there is unobstructed line of sight to four or more GPS satellites. [8] The GPS system is widely used by mariners onboard ships, giving them insight of their position and position of other vessels in vicinity. GPS was designed by the U. S. military. The concept started in the late '60s but the first satellite wasn't launched until February 1978. In 1989 the Magellan Corp. introduced the first hand-held GPS receiver. In 1992 GPS was used in Operation Desert Storm. On March 1996 the President decided to make GPS free for civilian users.“[8]

### **8.1. Basic concept of GPS**

„Concept of GPS is based on the known position of satellites and time. The “constellation” consists of 24 GPS satellites orbiting at almost 11,000 nautical miles above the center of the Earth. The satellites are arrayed in an inclined polar orbit. These orbits are inclined 55° from the plane of the equator. The satellites are arranged into six individual orbit planes

(four satellites occupy each orbit plane). These orbit planes are spaced at equal intervals around the Earth to provide global coverage.

Typically, 21 satellites are in use at any given time. In-orbit spares can be moved to fill a gap or to take over for a malfunctioning satellite. Schematically, the GPS satellite constellation appears like a dispersed cluster of bees orbiting the Earth. The pattern is designed such that a number of satellites can be seen at various directions from almost any location on Earth. Any given satellite completes an orbit around the Earth in 12 hours, so each satellite is moving with respect to an observer on the ground. Each satellite transmits signals in what is known as a pseudorandom code. This is a sequence of coded information that reliably can be transmitted at low power and recovered by the receiver. Latitude and longitude is why the GPS receiver is so useful to mariners.

The GPS unit also provides a value for altitude and precise time. While this is the only information that these expensive satellites tell us, it nonetheless is important information not otherwise easily obtained. Your GPS unit also provides a wide range of other information useful to the mariner. This information is computed within your GPS receiver by comparing your current position with an earlier position, or by comparing your current position to that of another location that you have stored in the receiver's memory. For example, the GPS unit derives information regarding your direction and speed by comparing your current coordinates to those at a slightly earlier time. The receiver provides the direction to steer the boat to a fixed object, and the object's distance from the receiver, by comparing your current coordinates with those of the objects toward which you are headed.“ [9]



Picture 10. GPS - Catamaran Olea

## 9. Conclusion

21st century is the period when greatest changes in modern equipment are being made. Each day can bring new and improved equipment that soon becomes essential in navigation. Unfortunately, the usage of modern equipment has become, not only a blessing, but also a burden to a navigator. It is harder than ever for a navigator to learn about new systems because there are many variations of equipment and that is most evident in display and controls.

Likewise, navigational officers rely too much on electronic equipment forgetting the so called „old means of navigation“. Praxis has proven that most of the mistakes are caused by human error, which, by deeper analysis, shows that mariners did not quite understand the concept of those aids. Also, even the most reliable equipment can malfunction and fail causing trouble in critical situations. Only experienced and educated personnel are able to identify the flaws in these situations. However, we can not deny the fact that navigation has become easier and safer in some ways.

Furthermore, the job of mariner is lot less stressful knowing that he or she is covered by all kinds of alarm and communication systems. In my opinion, true sailors, who realise that modernisation can be „a double-edged sword“, are more likely to have a good and safe voyage. Therefore, it is advised for all seafarers to take their time to learn more about the equipment that can ensure their safety and the safety of their crew and passengers, but also the vessel itself.





## 10. Glossary

Accuracy -	Točnost, preciznost	Machinery -	Strojevi, mašinerija
Acronym -	Akronim	Maintenance -	Održavanje
Acquisition -	Akvizicija, stjecanje	Malfunction -	Kvar, zastoje
Adequate -	Adekvatan, odgovarajući	Methods -	Metode
Authorities -	Vlasti	Noise -	Buka, Šum, galama
Artificial -	Umjetan	Orbit -	Orbita, putanja, kružiti
Aspect -	Silueta, izgled, stanovište	Oscillation -	Oscilacija
Beam -	Greda, mlaz, sponja	Pace -	Tempo, korak
Broad -	Širok, prostran, jasan, opći	Principle -	Načelo, princip
Capacitor -	Kondezator	Power -	Snaga, struja
Chip log -	Brzinomjer	Pulses -	Impulsi, puls, pulsiranje
Circuit -	(Strujni) krug	Respiration -	Disanje
Cluster -	Skup, grozd, grupa	Richest -	Najbogatiji, najvrijedniji
Compass -	Kompas	Route -	Put, pravac, smjer
Concept -	Koncept	Schematically -	Shematski
Constellation -	Konstelacij	Screwdriver -	Odvijač
Collision -	Sudar	Seaman -	Pomorac, mornar
Commercial -	Trgovački, komercijalan	Sextant -	Sekstant
Coverage -	Pokrivenost	Solid angle -	prostorni kut
Crucial -	Presudan, odlučan, prijelomni	Space based -	Smješten u svemiru
Disperse -	Raspršiti, rastjerati, rasuti	Subsequent -	Sljedeći
Display -	Zaslona, prikaz	Suitable -	Pogodan, prikladan,
Echo -	Jeka, odraz (na radarskom ekranu)	Suspicion -	Sumnja, nepovjerenje
Evident -	Evidentan		
To Enable -	Omogućiti	Troubleshooting -	Rješavanje problema
Endangers -	Ugrožavati, dovesti u opasnost	Tool -	Alat, pomagalo
Exercised -	Proveden	to Transmit -	Odaslati, emitirati
Flaws -	Nedostaci, mane	Variations -	Varijacije
Global -	Globalno	Vessel -	Brod, plovilo
Gyro compass -	Žiro kompas	Voyage -	Putovanje, poduhvat
Hand- Held -	Ručni	Voltage -	Napon, Voltaža
Hazard -	Opasnost, opasan poduhvat	Workload -	Opterećenje
Hydrographic -	Hidrografski		
IMO -	International Maritime Organization -		
	Međunarodna Pomorska Organizacija		
Inaccurate -	Neprecizan, netočan		
Inconsistent -	Nekonzistentnom		
Increasingly -	Povećavajući se		
Installation -	Montaža, instalacija, uređaj, objekt		
Important -	Važno		
Latitude -	Širina		
To Locate -	Locirati, pronaći, odrediti položaj		

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## *11.1. Pictures*

- Picture 1 - <https://www.agilemomentum.com/old-map-and-compass-concepts/> (11.6.2016.)

- Picture 2 - <http://www.brasscompass.com/sext-4in1885.htm> (12.6.2016.)

- Picture 3 - [https://en.wikipedia.org/wiki/Marine\\_chronometer](https://en.wikipedia.org/wiki/Marine_chronometer) (15.6.2016.)

Picture 4 – Fotografirao autor Šime Pedišić

Picture 5 – Fotografirao autor Šime Pedišić

Picture 6 – Fotografirao autor Šime Pedišić

Picture 7 - [https://en.wikipedia.org/wiki/Automatic\\_radar\\_plotting\\_aid](https://en.wikipedia.org/wiki/Automatic_radar_plotting_aid) (16.6.2016.)

- Picture 8 - <http://www.marineinsight.com/maritime-law/an-introduction-to-gross-maritime-distress-safety-system-gmdss/> (15.6.2016.)

Picture 9 – Fotografirao autor Šime Pedišić

Picture 10 – Fotografirao autor Šime Pedišić

## **Sažetak**

Tema završnog rada su Navigacijski instrumenti i oprema. U radu se govori općenito o načinu rada pojedinih instrumenata i opreme koja se nalazi na brodu, kako ta oprema funkcionira, koje su prednosti, koje su mane te kako se pomorac može služiti njima. Također, opisan je utjecaj sazrijevanja pomorstva kao gospodarske grane na razvitak opreme kroz povijest. Oprema i instrumenti su razvili više standarde sigurnosti te učinili plovidbu ugodnijom i sigurnijom. Usprkos razvitku instrumenata i opreme, pomorci se i danas savjetuju da se oslanjaju više na svoj vid te provjeravaju točnost na starim, ne-elektroničkim instrumentima. Razlog tomu je što tehnologija s vremenom postaje sve kompliciranija i teža za uporabu, te je sigurnost na prvom mjestu.

Ključne riječi: radar, GMDSS, ECDIS, GPS

## **Summary**

### **Navigation Instruments and Equipment**

Topic of the final paper is Navigation instruments and equipment. The paper generally discusses the mode of individual instruments and equipment aboard the ship, how this equipment works, their advantages and shortcomings and how a seafarer can use them. It also describes the impact that development of maritime industries has had on the equipment through the history. Instruments and equipment have developed higher standards of safety and made navigation more comfortable and safer. In spite of the development of instruments and equipment, even today mariners are advised to rely more on their vision and to check the accuracy with the old, non electronic instruments. The reason for it is the fact that nowadays technology has become more complicated and difficult to use, and the safety always comes first.

Key-words: radar, GMDSS, ECDIS, GPS