МІНІСТЕРСТВО ОСВІТИ І НАУКИ УКРАЇНИ

НАЦІОНАЛЬНИЙ АВІАЦІЙНИЙ УНІВЕРСИТЕТ

Факультет аеронавігації, електроніки та телекомунікацій
Кафедра авіаційних комп’ютерно-інтегрованих комплексів

ДОПУСТИТИ ДО ЗАХИСТУ
Завідувач випускової кафедри
__________Віктор СИНЄГЛАЗОВ
“____” __________2023р.

КВАЛІФІКАЦІЙНА РОБОТА

(ПОЯСНЮВАЛЬНА ЗАПИСКА)

ВИПУСНИКА ОСВІТНЬОГО СТУПЕННЯ

“МАГІСТР”

Спеціальність 151 «Автоматизація та комп'ютерно-інтегровані технології»

Освітньо-професійна програма «Комп’ютерно-інтегровані технологічні процеси і виробництва»

Тема: Цифровий гіромагнітний компас

Виконавець: студент групи ІЗ-225М Глібов Владислав Глібович

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Київ – 2023

MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE

NATIONAL AVIATION UNIVERSITY

Faculty of Aeronautics, Electronics and Telecommunications
Department of aviation computer-integrated systems

ADMIT TO THE DEFENSE

Head of the graduate department

__________ Viktor SYNEGLAZOV

“____” __________2023.

QUALIFICATION WORK

(EXPLANATORY NOTE)

GRADUATE OF AN EDUCATIONAL DEGREE

"MASTER"

Specialty 151 "Automation and computer-integrated technologies" Educational and professional program "Computer-integrated technological processes and production"

Topic: Digital gyromagnetic compass

Performer: student of group IZ-225M Vladyslav Hlibov

Supervisor: Associate Professor Mykola Vasylenko

Consultant of the section "Environmental protection" ____________ Radomska M.M.
(signature)

Consultant of the section "Labor protection" ___________ Kazhan K.I.
(signature)

Normative Controller: ___________ Filyashkin M.K.
(signature)

Kyiv - 2023

НАЦІОНАЛЬНИЙ АВІАЦІЙНИЙ УНІВЕРСИТЕТ

Факультет аеронавігації, електроніки та телекомунікацій

Кафедра авіаційних комп'ютерно-інтегрованих комплексів

Освітній ступінь магістр

Спеціальність: 151 " Автоматизація та комп'ютерно-інтегровані технології"

ЗАТВЕРДЖУЮ

Завідувач кафедри

Віктор СИНЄГЛАЗОВ

"____ " __________2023 р.

ЗАВДАННЯ

на виконання дипломної роботи студента

Глібова Владислава Глібовича

1. **Тема проекту (роботи):** "Цифровий гіромагнітний компас"

2. Термін виконання проекту (роботи): з 02.10.2023 р. до 18.12.2023 р.

3. Вихідні данні до проекту (роботи): Цифровий гіромагнітний компас, метод визначення курсу об'єкта, алгоритми калібрування гіроскопа та магнітного датчика, середовище Arduino IDE.

4. Зміст пояснювальної записки (перелік питань, що підлягають розробці): 1. Актуальність гіромагнітного компасу; 2. Огляд існуючих аналогів; 3. Огляд теоретичної інформації з приводу рішення поставленої задачі; 4. Розробка Цифрового гіромагнітного компасу; 5. Екологія; 6. Охорона праці.

5. Перелік обов'язкового графічного матеріалу: 1. Структурна схема гіромагнітного компасу; 2. Види існуючих аналогів; 3. Графічний інтерфейс гіромагнітного компасу; 4. Проведення моделювання

6. Календарний план-графік

№ пор.	Завдання	Термін виконання	Відмітка про виконання
1.	Отримання завдання	02.10.2023	
2.	Формування мети та основних завдань дослідження	05.10.2023	
3.	Аналіз існуючих аналогів	07.10.2023-25.10.2023	
4.	Теоретичний розгляд рішення задачі	27.10.2023 – 05.11.2023	
5.	Розробка структури гіромагнітного компасу	06.11.2023 – 20.11.2023	
6.	Розробка програмного та апаратного забезпечення цифрового гіромагнітного компасу	25.11.2023 – 14.12.2023	
7.	Оформлення пояснювальної записки	15.12.2023 – 17.12.2023	
8.	Підготовка презентації та роздаткового матеріалу	18.12.2023	

7. Консультанти з окремих розділів

Розділ	Консультант (посада, П.І.Б.)	Дата, підпис	
		Завдання видав	Завдання прийняв
Охорона праці	Доцент, Катерина КАЖАН		
Охорона навколишнього середовища	Доцент, Маргарита РАДОМСЬКА		

8. Дата видачі завдання: "02" жовтня 2023 р.

Керівник: ______________________ Микола ВАСИЛЕНКО
(підпис керівника) (П.І.Б.)

Завдання прийняв до виконання: ______________________ Владислав ГЛІБОВ
(підпис випускника) (П.І.Б.)

NATIONAL AVIATION UNIVERSITY

Faculty of Aeronautics, Electronics and Telecommunications

Department of aviation computer-integrated systems

Educational degree Master

Specialty: 151 "Automation and computer-integrated technologies"

APPROVED

Head of the Department

Viktor SYNEGLAZOV

“____” __________2023.

TASK

for the completion of the student's thesis

Hlibov Vladyslav Hlibovich

1. **Theme of the project (work):** "Digital gyromagnetic compass"

2. Term of the project (work): from 02.10.2023 to 18.12.2023.

3. Initial data for the project (work): A digital gyromagnetic compass, a method for determining the course of an object, algorithms for calibrating a gyroscope and a magnetic sensor, the Arduino IDE environment.

4. Contents of the explanatory note (list of issues to be developed): 1. Relevance of the gyromagnetic compass; 2. Review of existing analogues; 3. Review of theoretical information on the solution of the problem; 4. Development of a digital gyromagnetic compass; 5. Ecology; 6. Labor protection.

5. List of mandatory graphic material: 1. Block diagram of a gyromagnetic compass; 2. Types of existing analogs; 3. Graphical interface of a gyromagnetic compass; 4. Carrying out modeling

6. **Planned schedule:**

№	Task	Execution term	Execution mark
1.	Receiving a task	02.10.2023	
2.	Formation of the purpose and main objectives of the study	05.10.2023	
3.	Analysis of existing analogs	07.10.2023-25.10.2023	
4.	Theoretical consideration of the problem solution	27.10.2023 – 05.11.2023	
5.	Development of the gyromagnetic compass structure	06.11.2023 – 20.11.2023	
6.	Development of software and hardware for a digital gyromagnetic compass	25.11.2023 – 14.12.2023	
7.	Preparation of an explanatory note	15.12.2023 – 17.12.2023	
8.	Preparing a presentation and handouts	18.12.2023	

7. **Consultants for individual sections**

Section	Consultant (position, full name)	Date, signature	
		Tasks issued	Task accepted
Occupational Safety and Health	Associate Professor, Kateryna KAZHAN		
Protection of the environment	Associate Professor, Margarita RADOMSKAYA		

8. **Date of task receiving:** "October 02", 2023.

Diploma thesis supervisor ________________________ Mykola VASYLENKO
(signature)

Issued task accepted: ________________________ Vladyslav HLIBOV
(signature)

РЕФЕРАТ

Пояснювальна записка до кваліфікаційної роботи «Цифровий гіромагнітний компас»: 90с., 48 рис., 10 літературних джерел.

ЦИФРОВИЙ ГІРОМАГНІТНИЙ КОМПАС; ГІРОСКОПІЧНИЙ ДАТЧИК, МАГНІТНИЙ ДАТЧИК; КАЛІБРУВАННЯ.

Об'єкт дослідження – цифровий гіромагнітний компас.

Предмет дослідження – розробка цифрового гіромагнітного компасу.

Мета дослідження – розробка та дослідження цифрового гіромагнітного компасу.

Методи дослідження – теоретична фізика, теоретична електроніка, теорія програмування датчиків, теорія визначення положення в просторі на основі гіроскопа та магнітного датчиків.

Результат роботи - В результаті написання магістерської роботи був

розроблений цифровий гіромагнітний компас, який є більш дешевим за аналоги, але не поступається їм в характеристиках. В процесі було виконано наступні завдання:

1 Доведена актуальність теми та поставлені мета та задача;

2 Розглянуті існуючи види гіромагнітних компасів та їх недоліки;

3. Розроблена структура цифрового гіромагнітного компасу;

4. Розроблено програмне та апаратне забезпечення реалізації обраного методу;

5. Проведено експериментальне дослідження роботи розробленої системи.

ABSTRACT

Explanatory note to the qualification work "Digital gyromagnetic compass": 89 p., 48 figures, 10 references.

DIGITAL GYROMAGNETIC COMPASS; GYROSCOPIC SENSOR, MAGNETIC SENSOR; CALIBRATION.

The object of research is a digital gyromagnetic compass.

The subject of research is the development of a digital gyromagnetic compass.

Purpose of the study - development and research of a digital gyromagnetic compass.

Research methods - theoretical physics, theoretical electronics, theory of sensor programming, theory of position determination in space based on gyroscope and magnetic sensors.

The result of the work - As a result of writing the master's thesis was

a digital gyromagnetic compass was developed, which is cheaper than its analogues, but not inferior in characteristics. In the process, the following tasks were performed:

1 The relevance of the topic was proved and the goal and objective were set;

2 The existing types of gyromagnetic compasses and their disadvantages are considered;

3. The structure of a digital gyromagnetic compass is developed;

4. The software and hardware for the implementation of the chosen method are developed;

5. An experimental study of the developed system was carried out.

CONTENT

GLOSSARY

IMM – Inertial measuring module

MCD – Magnetic course device

ADC – Analog-to-digital converter

CTE – Control and testing equipment

FOG – non-breakable fiber optic

AVS –Angular velocity sensor

GSS – Gyroscopic sensor

MSD – Mean standard deviation

Introduction

Due to the rapid development of technology and the growing need for high-precision navigation solutions, gyromagnetic compasses used to determine direction in space are attracting growing interest among scientists and engineers. In response to this need for accurate and high-speed direction finding devices, the relevance of research in the field of digital gyromagnetic compasses is becoming undeniable.

Modern analog gyromagnetic compasses, despite their important functions, are limited in accuracy and speed of response to changing conditions. This necessitates the revision and improvement of these devices using new, more advanced technologies. Based on the above, the qualification work is aimed at studying, developing and implementing a digital gyromagnetic compass as an advanced and effective tool for measuring direction in space.

A review of the current state of technical development indicates the need to move from traditional analog gyromagnetic compasses to digital analogs. The advantages of the latter are higher accuracy, stability in different conditions and the ability to process data quickly, which makes them more attractive for a wide range of applications - from navigation and aviation to research in science.

Thus, consideration of the relevance of the topic puts into context the need to develop digital gyromagnetic compasses and sets the stage for further research and development aimed at improving and expanding the capabilities of these navigation devices.

Relevance of the topic

The modern development of oil and gas industry technologies is inextricably linked to increasing requirements for measurement accuracy and efficiency. One of the key components of navigation and direction measurement systems is gyromagnetic compasses. The ability to determine the direction of the magnetic north pole is critical to the safety and efficiency of many technical processes, including those in navigation, aviation, geological research, and other areas.

An analysis of the current state of the art of gyromagnetic compasses shows that existing analog systems, although effective, have limitations in terms of accuracy and speed of measurement, especially in conditions of high magnetic fields or sudden changes in temperature. Such limitations are due to the physical features of analog compasses and signal processing.

In this context, the relevance of the topic is manifested in the need to overcome the limitations of traditional gyromagnetic compasses by moving to digital solutions. Digital gyromagnetic compasses based on modern technologies provide higher accuracy, stability and response speed, which makes them attractive for applications in conditions of high dynamics and variable parameters.

Global experience also confirms the relevance of the problem and indicates the prospects for the development of digital gyromagnetic compasses. Examples of the successful use of digital technologies in aircraft and spacecraft navigation systems demonstrate the potential of these technologies to solve important problems in the field of navigation and direction measurement.

Thus, the relevance of the topic lies in the development and implementation of digital gyromagnetic compasses that can effectively meet modern requirements for accuracy, stability and speed of measurements in various technical applications.

Aims and objectives

Purpose of the qualification work:

The aim of this qualification work is to develop and improve a digital gyromagnetic compass to achieve higher accuracy and speed of directional measurements. This goal defines the general direction of research and development aimed at creating advanced technologies for precise navigation in a variety of environments.

Tasks of the qualification work:

Analysis of existing solutions:

To conduct a detailed analysis of modern digital gyromagnetic compasses, to determine their advantages and disadvantages in various operating conditions.

Algorithm development:

Develop a new direction measurement algorithm based on modern advances in digital sensors and artificial intelligence systems.

Prototyping:

Implement a prototype of a digital gyromagnetic compass using the new algorithm and test it in real-world conditions to evaluate its efficiency and accuracy.

Comparison with analogs:

Compare the test results of the developed prototype with existing analogs to determine the advantages and competitiveness of the proposed solution.

Provide recommendations for further opportunities to improve and utilize digital gyromagnetic compasses in various fields such as navigation, aviation, maritime, and others.

These tasks define specific steps to be taken to achieve the overall goal of the work. Analysis and development of new algorithms, prototyping and testing, as well as comparison of results with existing solutions define the methodology and approaches that will be used to achieve the goals.

CHAPTER 1
ANALYSIS OF EXISTING PROBLEMS AND THEORETICAL INFORMATION

1.1. Definition and history of the gyromagnetic compass

A gyromagnetic compass, also known as a gyroscopic compass, is a device that uses the gyromagnetic effect to determine direction. It includes a gyroscope (a device for maintaining stable orientation in space) and a magnetic system for determining the magnetic north direction. The gyroscope responds to the rotation of the device and allows you to determine the angle of deviation between the current direction of movement and the magnetic north direction.

The main advantages of gyromagnetic compasses include high resistance to magnetic influences and the possibility of using them in various conditions, including high latitudes and bouts of magnetic storms. They are often used in aviation, marine and other industries where accurate navigation is important.

However, it is important to note that gyromagnetic compasses can be more expensive and more difficult to maintain than other types of compasses, such as magnetic compasses or GPS navigation.

The history of the gyromagnetic compass is connected with the development of technology and navigation. Here is a brief overview of the history of gyromagnetic compasses:

The first compasses originated in China around the 11th century. They were basic magnetic arrows that pointed to magnetic north. These simple magnetic compasses were used for navigation on seas and rivers.

The invention of the gyroscope, which is a key component of gyromagnetic compasses, led to more accurate navigation tools. The first gyroscopes were developed in the 19th century.

In the 20th century, gyroscopes began to be used in combination with a magnetic system to create gyromagnetic compasses. These compasses proved particularly useful for airplanes and other aircraft where magnetic compasses were less reliable due to magnetic effects from aircraft equipment and construction.

In the 20th century, gyroscopic compasses became the standard means of navigation for aircraft and ships. They provided accurate direction determination and great resistance to magnetic influences.

Modern gyromagnetic compasses use advanced technologies such as electronics and microcontrollers to provide even greater accuracy and reliability. They are also integrated into the avionics along with other navigation systems such as GPS.

Outside of aviation and navigation, gyromagnetic compasses have also found applications in other industries, such as the space industry, the military, and ocean exploration.

The history of gyromagnetic compasses is marked by the constant development and improvement of navigation technologies, which contributed to the improvement of safety and efficiency of transport in various industries.

1.2. The structure and principle of operation of the gyromagnetic compass

The structure of a gyromagnetic compass can vary depending on the specific manufacturer and model, but the main components include a gyroscope and a magnetic system. Here is the general structure of a gyromagnetic compass:

The main component of a gyromagnetic compass is a gyroscope. A gyroscope is a device that has a special bearing that allows the object to maintain its orientation in space. In a gyromagnetic compass, a gyroscope is used to determine the angle of rotation of the device.

The magnetic system consists of magnetic sensors and other elements designed to determine the Earth's magnetic field. This system allows the gyromagnetic compass to determine magnetic north.

The received data from the gyroscope and magnetic system are processed by a built-in computer or a microcontroller. This component is responsible for calculating the direction and providing appropriate visual indications to the user.

Most gyro-magnetic compasses are equipped with a display that shows information about the current direction. This can be a digital screen or an analog compass dial.

Interfaces and accessories: Some gyro-magnetic compasses may have additional interfaces, such as buttons to control settings or connect to other navigation systems. They may also include additional features such as built-in GPS or an altimeter.

It is important to note that different models may have additional functions and features depending on their purpose and manufacturer.

The principle of operation of the gyromagnetic compass is based on the use of two main components: a gyroscope and a magnetic system. The gyroscope helps to maintain a constant orientation of the device in space, and the magnetic system determines the magnetic north direction. Here's how a gyromagnetic compass works:

A gyroscope is a device that is capable of maintaining constant orientation in space and reacts to any changes in the device's rotation. A gyromagnetic compass uses a gyroscope to determine the direction of rotation. If the gyroscope does not move and maintains its orientation, then it points in the north direction. If the device rotates, the gyroscope reacts to this movement and determines the angle of deviation from the magnetic north direction.

A gyromagnetic compass also includes a magnetic system that can determine magnetic north. This system can use magnetic sensors or other magnetic elements to detect the Earth's magnetic field and therefore determine the direction to north.

The gyroscope and magnetic system are used together to calculate the exact direction to the north. The gyroscope indicates the angle of deviation from the magnetic north direction, and the magnetic system determines the magnetic north itself. This data is then processed and displayed on the compass display so that the user can determine the current direction.

Gyromagnetic compasses are highly resistant to magnetic influences and provide accurate navigation, even in conditions where other types of compasses may not be effective enough. They are used in various fields such as aviation, marine, military and space industries.

1.3. Fields of use of gyromagnetic compasses

Gyromagnetic compasses, or gyroscopic compasses, play an important role in aviation for determining the direction of an aircraft. They are used on board airplanes, helicopters and other air vehicles. Here are some key aspects of gyromagnetic compasses in aviation:

Gyromagnetic compasses are one of the most accurate direction finding systems in air navigation. They can provide reliable data about the aircraft's magnetic heading, which is important for flight safety and navigation to the destination.

Gyro compasses are less susceptible to magnetic influences compared to conventional magnetic compasses. This is important because airplanes have magnetic fields that can distort the readings of conventional magnetic compasses. Gyromagnetic compasses have built-in compensators to help correct for these magnetic effects.

Gyro compasses perform well at high altitudes and at high speeds, making them ideal for aviation applications.

Gyromagnetic compass provides constant and stable information about the course of the aircraft, regardless of movements and turbulence.

A gyrocompass is often used as a back-up means of navigation when primary systems such as GPS or a magnetic compass fail for various reasons.

Gyro compasses are often used in pilot training because they allow you to learn how to adjust your actions to maintain a stable course.

All these features make gyromagnetic compasses important navigation tools in the world of aviation, where accuracy and reliability are very important for the safety and efficiency of flights.

1.4. Object and subject of the study

The object of study is a digital gyromagnetic compass, which is a component of modern navigation systems and is used in various technical devices. Analysis of the functions and characteristics of this object will allow us to understand its role in the modern technological environment.

The subject of the study is the specific aspects of digital gyromagnetic compasses, in particular their technical characteristics, directional accuracy, and ability to adapt to changing conditions. The study will include an analysis of modern models of digital gyromagnetic compasses and their capabilities.

Digital gyromagnetic compasses play a key role in a number of technological fields. They are used for precise navigation in mobile devices, automotive systems, aerospace vehicles, and other applications. Understanding their role and capabilities is important for further technological advancement.

This section defines the object and subject of the study, clearly outlining the scope of the analysis. A detailed study of digital gyromagnetic compasses in the context of their application and technical characteristics will lay the foundation for further conclusions and recommendations in the paper.

1.5. Formulating the problem

An important stage in our research is the formulation of the specific problem that we plan to solve. In light of the modern requirements and challenges associated with the use of digital gyromagnetic compasses, there are aspects that require attention and further improvement.

One of the key issues is the directional accuracy of digital gyromagnetic compasses. Errors that can be caused by external influences, magnetic field inhomogeneity, or technical limitations can lead to inaccurate navigation solutions.

Another relevant problem is the influence of electromagnetic fields on the operation of digital gyromagnetic compasses. Under certain conditions, measurements can be distorted, which can affect their accuracy and reliability.

Low efficiency of compensation algorithms for magnetic interference and other external influences can cause incorrect measurements. Research and improvement of these algorithms can positively affect the overall accuracy of gyromagnetic compasses.

Consideration of changing operating conditions, such as changes in the magnetic field during movement or the influence of other technical devices, is also an issue that should be considered. The flexibility and adaptability of gyromagnetic compasses to different usage scenarios becomes an important challenge for further improvement.

By formulating these problems, we identify specific aspects to work on during our research. Solving these problems can greatly improve the quality and performance of digital gyromagnetic compasses, making them more reliable and accurate in various operating conditions.

1.6. Critical analysis of existing solutions

In this section, we will critically analyze existing solutions in the field of digital gyromagnetic compasses. We will take a look at current solutions and identify their advantages and disadvantages, which will form the basis for further proposals for the improvement and development of these technologies.

One of the main advantages is the high accuracy of many existing digital gyromagnetic compasses. However, it should be borne in mind that this accuracy can be reduced by external factors such as magnetic interference or electromagnetic fields.

Many existing models exhibit high sensitivity to electromagnetic interference, which can lead to measurement distortions and insufficient reliability in real-world applications.

Some models use magnetic interference compensation algorithms, but their effectiveness can be limited. Reviewing and analyzing such algorithms is a key aspect to identify opportunities for improvement.

Some current models have shown significant progress in reducing energy consumption. However, energy efficiency remains an issue, especially for devices that operate in a stand-alone mode.

The cost of digital gyromagnetic compasses is another problematic area. In some cases, the high cost can make it difficult to widely adopt the technology, especially in the industrial and commercial segments.

As the technical ecosystem grows, integrating digital gyromagnetic compasses with other sensors and systems can be a challenge that requires additional consideration.

By critically analyzing existing solutions, we have identified key aspects that need to be improved. The conclusions offered in this section will form the basis for further recommendations and research in our work.

1.7. Justification of the need for research

The need to conduct research in the field of digital gyromagnetic compasses is determined by a number of objective and strategic factors, relating to both technical aspects and market and societal requirements.

With the deeper integration of gyromagnetic compasses into modern technical solutions, such as autonomous vehicles and drones, the importance of accurate measurements is growing. High accuracy becomes crucial to ensure reliable and efficient operation of such systems.

The increasing complexity and functionality of modern technologies creates a need for improved gyromagnetic compasses. Ensuring their compatibility, accuracy and stability is an important task for the effective use of these technologies in real-world conditions.

The market for digital gyromagnetic compasses is becoming increasingly competitive. Providing high quality and innovative solutions is strategically important to maintain and expand market position.

With the growing influence of electromagnetic fields from other electronic devices and infrastructure, the study and development of gyromagnetic compasses resistant to these influences is becoming an extremely important task.

The increasing demands on the quality and reliability of gyromagnetic compasses are driven by standards and certification requirements. Research and development of these devices is necessary to meet the high standards.

With the development of renewable energy sources that often require high directional accuracy (e.g., solar trackers), the importance of high-quality gyromagnetic compasses for spatial navigation becomes critical.

In justifying the need for research, we take into account important technical, market, and societal requirements that create the foundation for the development and improvement of digital gyromagnetic compasses.

1.8. Problem statement

The problem statement defines specific tasks and research areas aimed at solving the identified problems and achieving the set goals. The objectives of the study of digital gyromagnetic compasses include a number of key areas that need to be considered to obtain high-quality results.

One of the main tasks is to develop and improve algorithms for compensating for magnetic interference and electromagnetic effects. This is aimed at improving the stability and accuracy of measurements in different conditions.

The goal is to optimize the hardware and software of gyromagnetic compasses to ensure efficient energy use and extend battery life.

A detailed study of the effects of electromagnetic fields on the operation of gyromagnetic compasses should be conducted and methods of protection against this effect should be identified.

One of the main tasks is to improve navigation algorithms that use data from gyromagnetic compasses in order to achieve maximum accuracy and stability.

The best methods for integrating gyromagnetic compasses with other sensors should be studied and determined to ensure compatibility and high performance in different devices.

The objective is to create gyromagnetic compasses that effectively interact with modern electronics, ensuring stable and reliable operation in various electromagnetic conditions.

The task is to conduct experimental testing of the developed solutions and validate their effectiveness in real conditions.

By defining such specific tasks, we create a clear action plan for further research and development in the field of digital gyromagnetic compasses. These tasks define the key aspects that we will focus on to achieve successful and innovative results.

This section analyzes the existing problems and theoretical material related to digital gyromagnetic compasses. The relevance of the study is substantiated in connection with the growing importance of accurate measurements in modern technologies.

The theoretical review included an analysis of the technical characteristics of gyromagnetic compasses, their role in modern technologies and the impact of electromagnetic fields on their operation. It is noted that existing solutions have their advantages, but also face a number of problems, such as measurement accuracy, energy efficiency, and sensitivity to electromagnetic interference.

In the context of the identified problems, the main research problem is formulated - improving the quality and efficiency of digital gyromagnetic compasses. It is noted that this task is becoming relevant due to the growing requirements for measurement accuracy in modern technologies and the competitive market environment.

The section goes on to provide a critical analysis of existing solutions. The pros and cons of existing models of gyromagnetic compasses, such as their accuracy, sensitivity to electromagnetic interference, compensation algorithms, energy efficiency, and other parameters, are considered.

The section goes on to substantiate the need for research in this area. It is noted that improving measurement accuracy, adaptation to modern technologies, market competitiveness, and other factors make this work important and promising.

The final paragraph of the section formulates specific tasks for further research. The development of new compensation algorithms, improvement of energy efficiency, study of the impact of electromagnetic fields, improvement of navigation algorithms, and other areas are identified as key tasks.

The general conclusion from this chapter is that the research and development of digital gyromagnetic compasses has great potential to improve their efficiency and expand their application in modern technologies. The following sections will be devoted to the consideration of each task in detail and the presentation of research results.

CHAPTER 2
ANALYSIS OF EXISTING MODELS OF GYROMAGNETIC COMPASSES

There are many different models of gyro compasses designed by different manufacturers for different applications. Here are some examples of gyro compass models:

2.1. Honeywell HG1700 AG58

Honeywell HG1700 AG58: This gyro compass is manufactured by Honeywell and used in aviation applications. It provides accurate course data and can work in extreme conditions.

Fig. 2.1. Honeywell HG1700 AG58

Honeywell HG1700 AG58 is a gyroscopic compass designed and manufactured by the American company Honeywell. It is part of the Honeywell HG1700 family of gyroscopic compasses, which are designed for high-precision navigation in a variety of applications, particularly in the aviation industry. This compass uses quartz-based gyroscopes and accelerometers to measure rotational movements and spatial orientation.

Main characteristics of Honeywell HG1700 AG58:

This gyroscopic compass is characterized by high accuracy and stability of navigation data. It can provide reliable heading and bearing information, making it ideal for aviation applications where accuracy is key.

The HG1700 AG58 can operate under extreme conditions, including vibration, temperature changes, and altitude. This is important for aircraft that can be in different atmospheric conditions.

This type of gyro compass can be used in aircraft systems, military equipment, robots, navigation systems for ships and many other industries where precise navigation and orientation is required.

The HG1700 AG58 can include built-in test and calibration functions for reliability and diagnostics.

This gyro compass, like other similar models, plays an important role in maintaining accuracy and safety in air and other modes of transportation.

2.2. KVH DSP-1760 FOG

KVH DSP-1760 FOG: This is another aviation gyro compass manufactured by KVH Industries. It uses non-breakable fiber optic (FOG) technology and provides stability and precision for aircraft navigation.

Fig. 2.2. KVH DSP-1760 FOG

KVH Industries manufactures the KVH DSP-1760 FOG Gyro Compass, which is a high-precision inertial compass that uses non-breakable fiber optic (FOG) technology to measure rotational motion and determine direction and orientation. Here is more information about this gyro compass:

Non-disruptive fiber optic (FOG): The KVH DSP-1760 uses non-disruptive fiber optic technology to measure angular velocity. This technology guarantees high accuracy and stability of measurements of navigation parameters.

This gyro compass provides highly accurate heading and orientation measurements, making it suitable for demanding applications such as aviation and space industries.

The DSP-1760 can operate under conditions of high vibration, turbulence and temperature changes, making it an excellent choice for aircraft and ships operating in various weather conditions.

This type of gyro compass is used in aircraft systems, spacecraft, and other applications where high accuracy of inertial navigation is important.

The DSP-1760 can be integrated into onboard systems for navigation and control, and it can provide navigation data such as course, speed and altitude.

The KVH DSP-1760 FOG Gyro Compass is an essential component for high-precision navigation in the aviation and space industries, where accuracy and reliability are critical to safety and mission success.

2.3. Northrop Grumman LN-100G

Northrop Grumman LN-100G: This gyro compass is used in aerospace applications and was developed by Northrop Grumman. It provides accurate orientation and heading data in conditions of high gravity gradients.

Fig. 2.3. Northrop Grumman LN-100G:

These models represent only a few examples of gyro compasses, and there are many other models from different manufacturers, each of which can be designed for specific needs and applications.

Northrop Grumman LN-100G gyroscope compass is an important component of military equipment and aviation systems designed to measure rotational movements and navigation. It is developed by Northrop Grumman, one of the leading military industrial companies of the United States of America. Here is more information about this gyro compass:

The LN-100G is intended for use in military equipment, including military aircraft, helicopters, drones and other aviation and defense systems. It helps determine the orientation and direction of movement of these systems in real time.

The LN-100G uses non-disruptive fiber optic (FOG) technology to measure rotational angular velocity. This provides high accuracy and stability of measurements of navigation parameters.

This gyro compass provides very high accuracy and reliability under operational conditions, making it ideal for military applications where reliability is critical.

It can operate in conditions of high vibration, turbulence and temperature changes, making it suitable for various operating environments.

The LN-100G can be integrated with other onboard systems for navigation, control and data acquisition. It can provide course, speed, altitude and orientation data to pilots and automatic control systems.

The LN-100G is an essential component for military navigation, fire control, and precision warfare and reconnaissance missions.

This gyro compass is critical to the successful operation and safety of military and aircraft systems and meets the high standards of accuracy and reliability required in military applications.

2.4. Gyromagnetic compass based on MEMS sensors and Digital gyromagnetic compass

Gyromagnetic compass based on MEMS (Microelectromechanical systems) is a modern type of compass that uses microelectromechanical sensors to measure rotational movements and a magnetic sensor to determine direction based on the Earth's magnetic field.

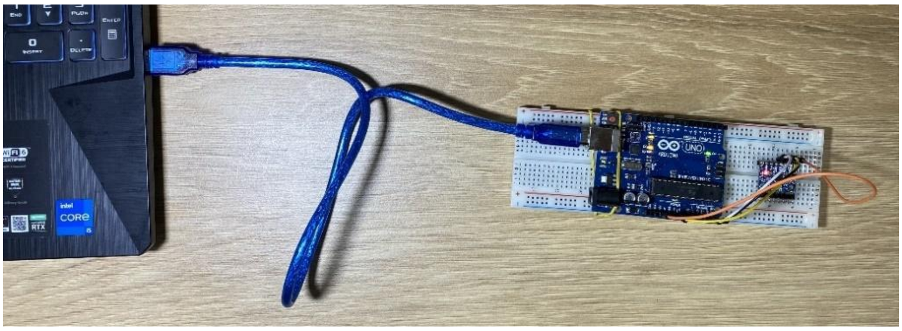

Fig. 2.4. Prototype of Gyromagnetic compass based on MEMS sensors

MEMS is a technology that allows the creation of miniature mechanical and electrical systems at the microscopic level. MEMS-based gyromagnetic compasses use microscopic gyroscopes and accelerometers to measure the rotational movements of a ship or aircraft.

A magnetic sensor that responds to the Earth's magnetic field is used to determine the direction. This sensor allows you to determine the magnetic azimuth, that is, the direction to the north.

Gyroscopes and accelerometers help to determine the orientation of the device in space. Information received from gyroscopes and accelerometers can be processed and integrated with data from a magnetic sensor to accurately determine direction.

The main advantage of gyroscopic compasses based on MEMS is their miniaturization and lightness. They have compact dimensions and low mass, which makes them ideal for use in mobile devices such as smartphones, navigators and drones.

Many MEMS-based gyro compasses have low power consumption, allowing them to be used in power-constrained devices such as portable electronic devices.

A gyromagnetic compass based on MEMS sensors has numerous advantages, but can also face a number of problems and limitations:

MEMS sensors can be sensitive to vibration and turbulence, especially in moving vehicles such as cars, ships, or airplanes. Vibrations can lead to inaccuracies in measurements and require filtering and compensation to obtain accurate results.

MEMS-based gyrocompasses can be vulnerable to magnetic interference, such as metallic objects or electromagnetic interference. This can lead to distortions in measurements and require correction.

MEMS sensors can also be vulnerable to electromagnetic interference that can arise from various electronic devices and communication systems. This can distort the magnetic fields and affect the accuracy of the compass.

MEMS-based gyro compasses may require regular calibration to ensure accuracy. Calibration may require special equipment and procedures.

MEMS sensors can be subject to chipping or failure due to exposure to extreme conditions such as strong shocks or high temperatures. This may affect the reliability of the device.

MEMS-based gyro compasses can have large errors, especially with prolonged use, which may require regular adjustments.

Despite these problems, MEMS-based gyrocompasses have become popular due to their compactness, low cost, and wide application in the automotive industry, aerospace applications, smartphones, drones, military systems, and other modern technological devices for navigation and orientation. Manufacturers are constantly improving this technology to reduce flaws and improve reliability and accuracy.

A digital gyromagnetic compass is a type of compass that uses digital sensors and computing technology to determine heading and orientation based on the Earth's magnetic field and the device's rotational movements. Here are more details on digital gyro magnetic compasses:

The digital gyromagnetic compass is equipped with a magnetic sensor that measures the magnetic field at the location of the compass. This sensor determines the direction to the North Pole using the Earth's magnetic field.

In addition to the magnetic sensor, the digital gyromagnetic compass can be equipped with a gyroscope and an accelerometer. The gyroscope measures the rotational movements of the device, and the accelerometer measures the acceleration. This additional data is used to determine the orientation of the device in space.

Information from the magnetic sensor, gyroscope and accelerometer is processed by an embedded processor or microcontroller to determine the course and orientation of the device. This can happen through the use of filtering algorithms and calculations such as the Kalman filter.

The calculation results can be displayed on the device display where the user can check the direction and orientation. It can be displayed in degrees, vectors on the map or in other ways.

Digital gyromagnetic compasses are widely used in various devices such as smartphones, tablets, navigators, drones, mobile robots, sports watches and other electronic gadgets. They allow users to determine their course and orientation to navigate in space.

To ensure accurate results, digital gyro-magnetic compasses may require periodic calibration, especially when used for the first time or after a change of location. Calibration helps eliminate the influence of magnetic and electromagnetic interference on the device.

Digital gyromagnetic compasses have become an integral part of modern electronic devices and are used in various areas of life, including navigation, sports, tourism and many other applications.

Digital gyro-magnetic compasses have their advantages, but they can also face a number of problems and limitations.

Digital gyro-magnetic compasses can be sensitive to magnetic and electromagnetic interference, such as metal objects, electrical wires, electronic devices, and other sources of interference. This can lead to inaccuracies in determining the course.

Some digital gyro-magnetic compasses may require periodic calibration to ensure accuracy and compensate for magnetic effects. Calibration can be an important task, especially when used in variable conditions or in a new location.

Digital gyro magnetic compasses can be sensitive to vibration and turbulence, especially in moving vehicles. Vibrations can cause compass drift and require filtering and compensation.

The Earth's magnetic field is not constant and can vary depending on geographic location and time. This can affect the accuracy of the gyro-magnetic compass, and in some cases recalibration may be necessary.

Depending on the specific model and use, digital gyromagnetic compasses may require significant power consumption, which may affect the device's battery life.

At high or low latitudes where the Earth's magnetic field tilts significantly, digital gyromagnetic compasses may be less effective and may require special correction.

Some high-precision digital gyro-magnetic compasses can be expensive, making them less affordable for some applications.

Despite these problems, digital gyromagnetic compasses are used in a wide range of applications and generally provide satisfactory accuracy and reliability under most conditions. Understanding these issues and taking appropriate precautions can help ensure optimal performance of these compasses.

Digital gyro magnetic compasses are used in a variety of industries, including consumer electronics, navigation systems, aviation, robotics, and many other fields.

1. Smartphones and tablets: Most iPhone models have built-in digital gyromagnetic compasses that are used for navigation and orientation.
2. Car navigators: Some models of car navigators from Garmin are equipped with digital gyromagnetic compasses for accurate navigation on the road.
3. Aviation: Digital gyromagnetic compasses are used in many modern avionics systems, such as the Garmin G1000 system, for aircraft navigation and orientation.
4. Marine navigation: Marine navigation systems such as the Raymarine Axiom use digital gyromagnetic compasses to determine a vessel's course.
5. Drones: Some drones, such as the DJI Phantom 4 Pro, use digital gyromagnetic compasses for stabilization and navigation during flight.

MEMS-based gyromagnetic compasses and digital gyromagnetic compasses are actually two different types of compasses, and their differences lie in the technology and principles of operation:

1. Sensor technology: A MEMS-based gyromagnetic compass uses microscopic mechanical sensors, such as microelectromechanical gyroscopes and

accelerometers, to measure rotational motion and acceleration, and a magnetic sensor to determine magnetic direction. It is able to determine the course and orientation of the device based on these measurements. A digital gyromagnetic compass uses digital sensors, such as magnetic sensors and possibly gyroscopes and accelerometers, to measure the magnetic field and rotational motions. Information from these sensors is processed by a built-in processor, and the results are presented in digital form.

2. Size and compactness: A MEMS-based gyromagnetic compass is often smaller in size and weight, making it ideal for use in mobile devices such as smartphones and tablets. A digital gyro magnetic compass can be less compact and lightweight, but can also include additional computing power and functionality, making it suitable for a wider range of applications.
3. Difficulty and accuracy: A MEMS-based gyromagnetic compass has limited accuracy and may require additional steps, such as calibration, to achieve greater accuracy. A digital gyromagnetic compass usually provides higher accuracy due to more advanced computing technology and the ability to correct errors in real time.
4. Application: A MEMS-based gyromagnetic compass is commonly used in mobile devices for navigation, geolocation, and heading. The digital gyro magnetic compass has a wider range of applications, including navigation in the automotive industry, robotics, aviation, aerospace, surveying, sports watches and many other industries.

When choosing between a MEMS-based gyro magnetic compass and a digital gyro magnetic compass, it is important to consider the specific needs and applications for which you plan to use the compass, as well as the accuracy and scale of your project or device.

CHAPTER 3

THEORETICAL INFORMATION ABOUT THE SOLUTION OF THE PROBLEM

3.1. Arduino UNO R3 board

Fig. 3.1. Arduino UNO R3 board

The Arduino UNO R3 is a development platform based on the ATmega328 microcontroller. It is a member of the Arduino family of boards and uses open source code to build electronic devices. The main features of the board include:

ATmega328 microcontroller: This microcontroller has built-in Flash, EEPROM, and SRAM memory, making it ideal for embedded applications.

I/O: The board has digital and analog pins that can be programmatically configured to input or output signals.

USB interface: For programming and to provide interaction with a computer.

Power supply: The board can be powered by USB or an external power supply.

The Arduino is developed using the Wiring programming language, which is based on C/C++. Developers can easily program the microcontroller using the Arduino Integrated Development Environment (IDE). The code is uploaded to the board via the USB interface.

The Arduino UNO R3 has advanced features thanks to the expansion connectors (buses). This allows you to add a variety of modules and sensors to extend the functionality. It is also important to consider using different libraries and additional components.

In the case of a gyromagnetic compass, an Arduino board is used to read data from a gyroscope and magnetometer, process this data, and then orient the system in space. The board's interface allows for easy interaction with various sensors and filtering algorithms.

The Arduino UNO R3 is a powerful tool for developing embedded systems, and its capabilities are easily expanded with a variety of modules and sensors. This board is an important part of the gyromagnetic compass, providing a convenient interface for interacting with other electronic components and software.

3.2. HMC5883L module (Magnetometer)

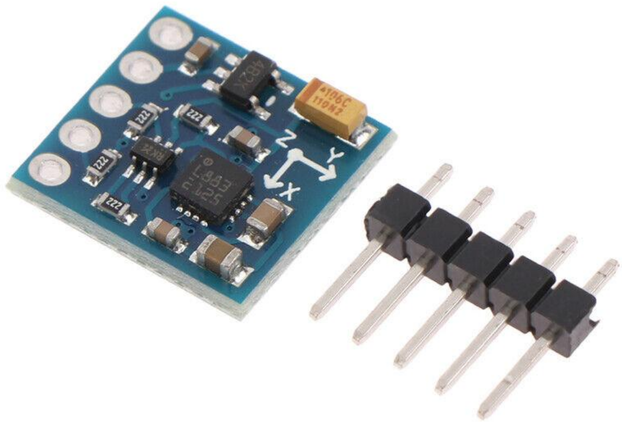

Fig. 3.2. HMC5883L module

The HMC5883L module is a digital magnetometer designed to measure magnetic field in three dimensions. It utilizes three industry-standard sensors to provide accurate magnetic field measurements in multiple directions. The main features of the module include:

- Measurement range: The HMC5883L module can measure magnetic field in the range of -8 to +8 Gauss.

- Interface: The interface is via I2C (Inter-Integrated Circuit), which allows it to be easily integrated with a variety of microcontrollers, including Arduino.
- Resolution: Provides high resolution for accurate magnetic field measurement.

The HMC5883L magnetometer uses Hall sensors to measure the magnetic field. Changes in the direction of the magnetic field result in changes in the output signal of the sensors. These changes are converted into a digital form and sent via an I2C interface.

Technical specifications:

- Operating voltage range: 3.3V or 5V (depending on the module version).
- Operating current: About 100 mA.
- I2C data transfer rate: Up to 400 bits per second.

The HMC5883L module is used in a gyromagnetic compass to measure the Earth's magnetic field. Its data is used to determine the magnetic direction, which, together with the data from the gyroscope, allows to determine the exact orientation of the system.

The HMC5883L module is a key component of a gyromagnetic compass that provides accurate magnetic field measurement. Its integration with the Arduino board and other sensors allows you to create accurate and efficient gyromagnetic compasses for a variety of applications.

3.3. GY-BMI160 module (Gyroscope)

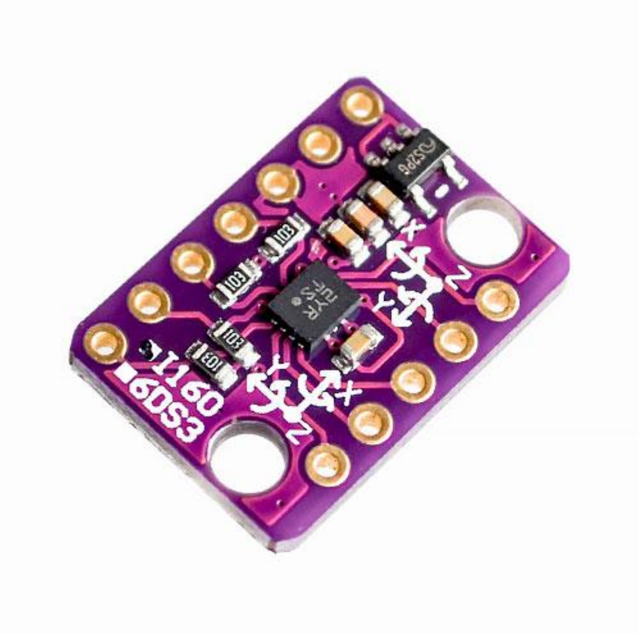

Fig 3.3. GY-BMI160 module

The GY-BMI160 module is a gyroscope and accelerometer designed to measure rotational motion and acceleration in three dimensions. This module is an inertial system that allows you to determine the orientation of an object in space. The main characteristics of the module include:

- Triaxial gyroscope and accelerometer: Provides measurements of rotational motion and acceleration in three dimensions.
- Interface: Typically uses an SPI or I2C interface to communicate with a microcontroller.
- Measurement range: The gyroscope and accelerometer can work in different modes and measure values according to the preset ranges.

The gyroscope uses the principle of angular momentum conservation to measure rotational motion, while the accelerometer uses acceleration to determine the orientation of an object. Both sensors can work synergistically to provide accurate motion data.

Specifications:

- Operating voltage range: 1.71V to 3.6V.
- Interface: I2C or SPI.
- Gyroscope resolution: Depends on the operating mode, such as 125, 250, 500, 1000, 2000 degrees per second.
- Accelerometer resolution: Depends on the operating mode, e.g. 2, 4, 8, 16 g.

The GY-BMI160 module in a gyromagnetic compass is used to measure rotational motion and acceleration, which are then used to determine the exact orientation of the system in space, together with data from the magnetometer.

The GY-BMI160 module is an essential component for building a gyromagnetic compass that can measure not only magnetic field but also rotational motion and acceleration. Its high resolution and the ability to operate in different modes make it an effective tool for determining accurate orientation in space.

3.4. Receiving, analyzing, and processing data from modules

3.4.1. Acquiring data from the modules

To acquire data from the HMC5883L via I2C, the Arduino UNO R3 establishes a connection to the magnetometer and initializes the data reading from the appropriate registers. Display the read magnetic field (direction) values in physical units (Gauss) and take into account any corrections to compensate for the influence of magnetic deviations from the Earth.

The GY-BMI160 can also be read via I2C or SPI, depending on the selected interface. The gyroscope data contains the angular velocity of rotation and the accelerometer data contains the acceleration in three dimensions.

3.4.2. Data analysis

Magnetometer data can be analyzed to determine orientation relative to magnetic north. This can include calculating the azimuth angle and declination.

Gyro data is analyzed to determine rotation around the three dimensions of space. Algorithms can be applied to detect angular motions and integrate them to determine the orientation angle.

The accelerometer data is used to determine the tilt of the system and calculate the orientation relative to the vertical axis.

3.4.3. Data processing

Apply data filtering to remove noise and correct inaccuracies. Different filters can be used, such as a Kalman filter or a low-pass filter.

Use of combination algorithms, such as complementary filters, to combine data from the gyroscope, accelerometer, and magnetometer to obtain an accurate system orientation.

Integrates data from all sensors to determine the absolute orientation of the system in space.

Calculation of azimuth angle, declination, and other parameters that describe the position of the system relative to geographic coordinates.

Receiving, analyzing, and processing data from modules is a key step in creating an accurate and reliable gyromagnetic compass.

Correct data processing allows to achieve high accuracy of the system orientation determination and ensures optimal performance of the gyromagnetic compass in various operating conditions.

3.5. Data filtering, complexation algorithm

3.5.1. Kalman filter

The Kalman filter is a mathematical algorithm used to process data and filter out noise in measurements. First developed by Rudolf Kalman in 1960, this filter is widely used in a variety of fields, including navigation, aviation, robotics, and other areas where measurement accuracy is important.

The Kalman filter is based on mathematical models of systems and predictions to calculate an optimal estimate of the system's state over time. The basic idea is to combine information from sensor measurements and system model predictions to get the most accurate estimate of the system state.

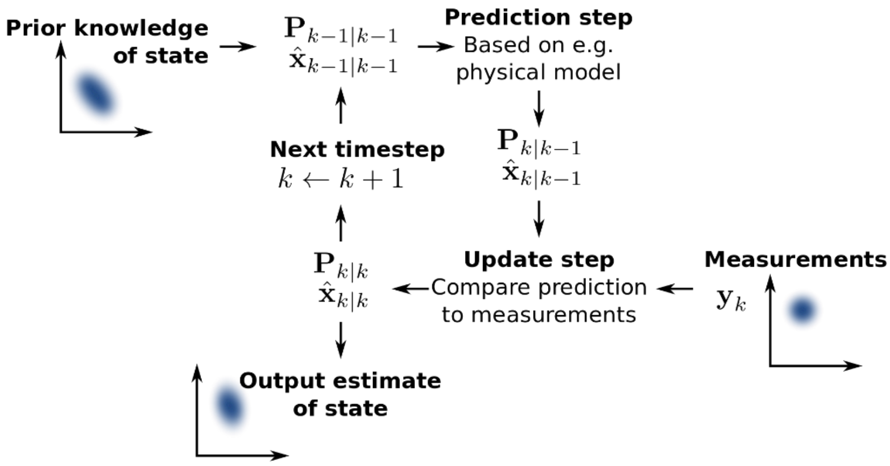

Fig 3.4. Kalman filter

Main steps of the algorithm:

1. Initialization: Setting initial values for the scores and covariance matrices.
2. Predict: Estimating the state of the system based on the previous information and the system model. Calculates the prediction of the score and the prediction of the covariance matrix.
3. Update: Receive new measurements from sensors. Calculate the weighted score based on the forecast and new measurements. Update the covariance matrix.
4. Repeat: Repeat the prediction and update in each measurement cycle.

In the context of a gyromagnetic compass, the Kalman filter can be used to combine data from a gyroscope, accelerometer, and magnetometer.

Gyroscope: Used to predict the rotational motion of the system.

Accelerometer: Helps determine orientation relative to the vertical axis.

Magnetometer: Used to correct direction estimates based on the Earth's magnetic field.

Advantages:

- Works effectively in environments with a lot of noise and uncertainty.
- Ideal for combining data from different sensors.

Limitations:

- Requires a priori knowledge of the system and accurate noise parameters.
- Consumes some computing power, making it less efficient for implementation on less resource-intensive platforms.

The Kalman filter is a powerful tool for combining and filtering data from different sensors in a gyromagnetic compass. The use of this filter allows to achieve high accuracy and stability in determining the orientation of the system in space, reducing the influence of noise and random measurements.

3.5.2. Low-Pass Filter

A Low-Pass Filter (LPF) is an electronic filter that passes signals with low frequencies and suppresses signals with high frequencies. In the context of a gyromagnetic compass, the LPF is used to smooth the signals coming from the sensors and to remove high frequency noise.

Low-pass filters allow signals with low frequencies to pass through and suppress signals with high frequencies. They work by smoothing out rapid changes in the signal, thereby highlighting smoother, slower changes. This results in less noise and more stable values.

Main characteristics:

Cutoff Frequency: This is the frequency up to which the filter allows signals to pass without losing intensity.

Damping Ratio: Determines how quickly the filter responds to changes.

Filter Type: Can be implemented as an electronic or digital filter.

The low-pass filter can be used to smooth the values coming from the gyroscope and accelerometer. Helps to reduce high-frequency noise that can occur when the system moves suddenly.

Types of Low Pass Filters:

- Exponential Moving Average (EMA):
  - Simple and easy to implement.
  - Suitable for low-frequency signals.
- Infinite Impulse Response (IIR):
  - A linear filter that can be implemented in hardware or software.
  - It is capable of filtering signals at different frequencies.
- Finite Impulse Response (FIR):
  - A nonlinear filter used for precise smoothing and advanced frequency control.

Advantages:

- Reduced noise and high frequency interference.
- Improved measurement stability and accuracy.

Limitations:

- Response delay can result in loss of information about rapid signal changes.
- Requires customization for optimal adjustment to specific conditions.

A low-pass filter is an important element of signal processing in a gyromagnetic compass. Its use allows to effectively smooth and filter the input data, which increases the accuracy and stability of determining the system's orientation in space.

3.5.3. Complementary Filter

The complementary filter is an algorithm for combining data from different sensors to obtain an accurate and stable estimate of the system state. In a gyromagnetic compass, it is often used to combine information from the gyroscope and accelerometer to determine orientation in space.

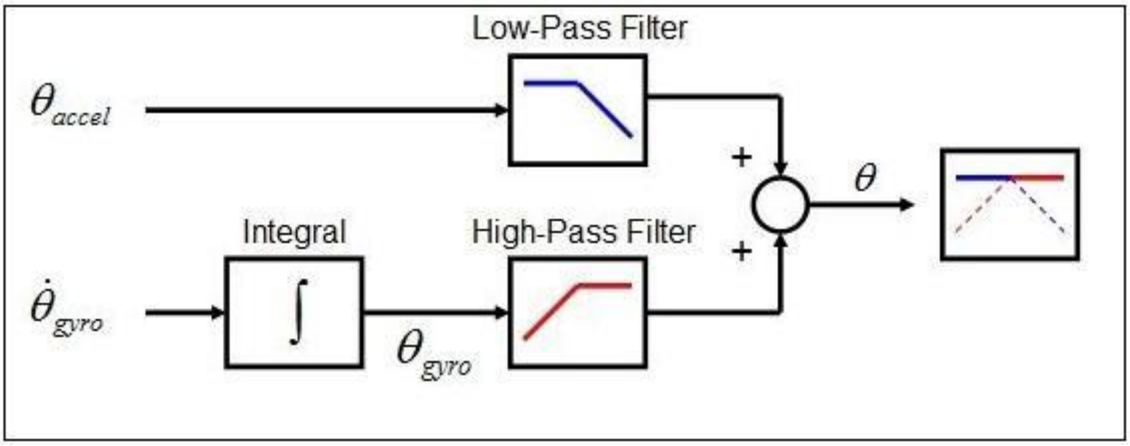

Fig. 3.5. Complementary Filter

A complementary filter uses two main components: a Low-Pass Filter (LPF) and a High-Pass Filter (HPF). The basic idea is to use the low-pass filter to smooth out the signals from the accelerometer (low frequency components) and the high-pass filter for the gyroscope (high frequency components).

Main steps of the algorithm:

1. Data acquisition: Receive measurements from the gyroscope and accelerometer.
2. Filtering of Gyroscopic Data: Use a high-pass filter to remove high-frequency components from the gyroscopic data.
3. Filter Accelerometer Data: Use a low-pass filter to remove low-frequency components from accelerometer data.
4. Merge Data: Combine the filtered data from the gyroscope and accelerometer.
5. Orientation Computation: Determine the system's orientation based on the combined data.

Use in a gyromagnetic compass

Gyroscope: The high-pass filter allows only fast changes in orientation to be taken into account, which helps to avoid gyroscope drift.

Accelerometer: The low-pass filter accounts for slow changes in orientation, ensuring system stability.

Advantages:

- Reduces gyro drift and compensates for accelerometer noise.
- High speed response to changes.

Limitations:

- Requires certain settings to optimize for specific tasks.
- Suitable only for certain operating conditions.

The complementary filter is an effective method for combining and filtering data from the gyroscope and accelerometer, which allows you to obtain an accurate and stable estimate of the system's orientation in space. Its use helps to improve the effectiveness of the gyromagnetic compass in the face of various challenges and obstacles.

In this section the key aspects of creating a digital gyromagnetic compass are considered. In the context of this section, the main components of the system and their theoretical aspects are described.

Starting with the Arduino UNO R3 board, the theoretical aspects of its use as a microcontroller for controlling a gyromagnetic compass are covered. A further study of the HMC5883L (magnetometer) and GY-BMI160 (gyroscope and accelerometer) modules provides an understanding of their operation and the measurements they make.

Special emphasis is placed on the stages of obtaining, analyzing, and processing data from the modules. It describes how the gyroscope and accelerometer jointly determine the orientation of the system in space, and how the magnetometer data is corrected to compensate for magnetic deviations.

Next, various methods of data filtering are presented. The Kalman filter, low-pass filter, and complementary filter are justified as means of reducing noise, improving measurement accuracy and stability.

In general, the theoretical basis of this section allows you to understand the principles of functioning and interaction of gyromagnetic compass components, which is the basis for further development and adjustment of this system.

CHAPTER 4
EXPERIMENTAL SOLUTION OF THE STATED PROBLEM

4.1. Components for assembling the device

This section provides a detailed overview of the steps and components used in the development and experimental solution of the digital gyromagnetic compass. Starting with the description of the assembly elements used, such as the MB-102 breadboard and AM-BM USB cable and ending with the process of preparing the software using the Arduino IDE and Processing.

Further consideration of the assembly and programming steps will allow you to gain insight into the practical implementation of a digital gyromagnetic compass.

Let's examine the specifics of the gyromagnetic compass employed in crafting the device:

- HMC5883L module (Magnetometer)
- GY-BMI160 module (Gyroscope)
- Arduino UNO R3
- Breadboard MB-102 with 830 openings
- USB cable Arduino type AM-BM
- Set of jump wires

We've previously discussed the HMC5883L module (Magnetometer), GY-BMI160 module (Gyroscope), and the control board Arduino UNO R3, so let's proceed to the next set of components.

4.1.1. MB-102 breadboard

The MB-102 breadboard is a basic tool for experimenting with electronics and prototyping circuits. It consists of a plastic base with holes for inserting electronic components. Its main advantage is the ease of installation and connection of various elements without the need for soldering.

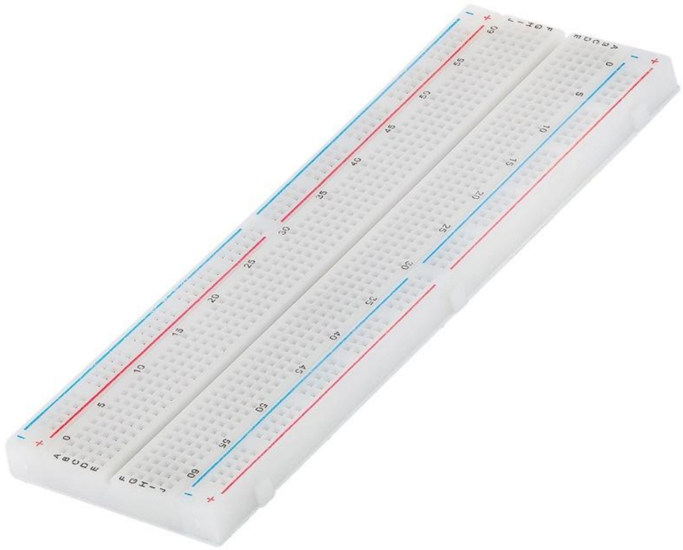

Fig. 4.1. MB-102 breadboard

The MB-102 is used to create a prototype gyromagnetic compass where various components can be easily placed and reconnected to test different circuits. It allows easy connection and disconnection of components without risk of damage. Ideal for the prototyping phase before final assembly.

Advantages:

- Ease of use: The MB-102 is easy to use, making it an ideal tool for startups and electronic projects.
- Safety: No soldering is required, reducing the risk of component damage and making it easy to use, especially for beginners.

Connecting during the installation process of the gyromagnetic compass:

- Power supply: Connecting the power supply voltage to power the entire circuit.
- Arduino connection: Location and connection of the Arduino microcontroller to control and read data from the sensors.
- Sensor connections: Locate and connect the gyroscope and magnetic sensor to measure rotation and magnetic field.
- Connecting to the USB cable: Provide communication and power using an AM-BM type USB cable.

4.1.2. Arduino USB cable type AM-BM

Fig. 4.2. Arduino USB cable type AM-BM

The AM-BM USB cable is used to provide power and data transfer between the Arduino board and a computer or other device. The terms "AM" and "BM" indicate the types of connectors on each end of the cable: "AM" (Type-A Male) is a standard USB Type-A connector and "BM" (Type-B Male) is a USB Type-B connector.

The USB cable provides the necessary power for the Arduino and allows communication with a computer for flashing the microcontroller and debugging the software. The cable is used to transfer program code to the Arduino and to debug the program.

Advantages:

- Versatility: The standard AM-BM type USB cable is a widely used standard, making it easy to find or replace the cable if necessary.
- Reliability: The cable provides stable power and data transmission, which is important for the correct operation of the microcontroller and interaction with the computer.

Connection during the installation of the gyromagnetic compass:

- Connecting to the Arduino: One end of the cable connects to the USB port on the Arduino board.

- Connecting to the power supply: The other end of the cable connects to a power supply or computer, providing power to the Arduino and the entire circuit.
- Providing communication: Providing communication between the Arduino and the computer for firmware and software debugging.

This cable is a necessary means for the Arduino to effectively communicate with the computer and provide the necessary power for the gyromagnetic compass to work properly.

4.1.3. Jumpers

Description:

Jumpers are elementary components of an electronic lab board (Lab Board) that are used to provide electrical connections between electronic components on the board. They are short, wire-like elements made of a metal material that allow connections to be made between the corresponding holes.

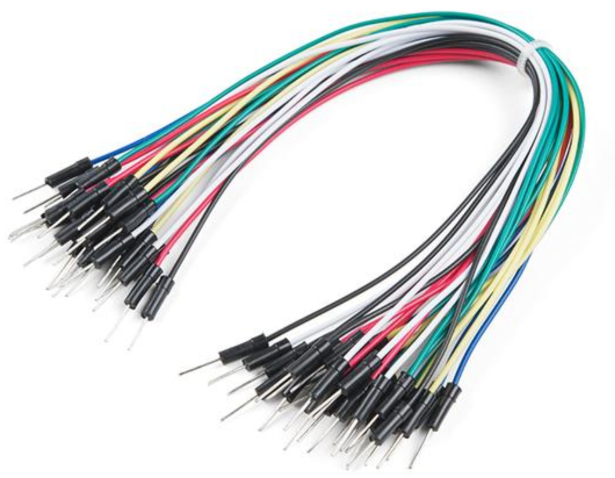

Fig 4.3. Jumper wires

Jumpers are used to create electrical connections between the corresponding holes in the Board, allowing electronic components to be connected to each other. These wire-like elements allow power and signals to be routed from one component to another without the need for soldering.

Advantages:

- Ease of use: Jumpers make it easy to change connections between components without the need for tools.
- Convenience of prototyping: Their presence allows you to effectively prototype electronic circuits and change their structure during development.

Jumpers are used to connect the power supply to the appropriate connections on the Board. They allow you to connect electronic components, such as a gyroscope, magnetic sensor, and Arduino microcontroller, to each other. Guarantees effective electrical contact between the various circuit elements for reliable operation of the gyromagnetic compass.

The wire length should not exceed 30 cm, although in certain situations, such as supplying power to low-power devices, it might be feasible to use longer wires. If transmitting power, data, or binary signals over an extended distance, it is advisable to use a cable with a suitable protocol for the application.

Jumpers are important components for making electrical connections on the BraidBoard, and they play a key role in ensuring that the gyromagnetic compass works effectively during experimental testing.

4.2. Gyromagnetic compass scheme

We are familiar with the functioning of all components, so let's discuss the schematic of the prototype that will be assembled.

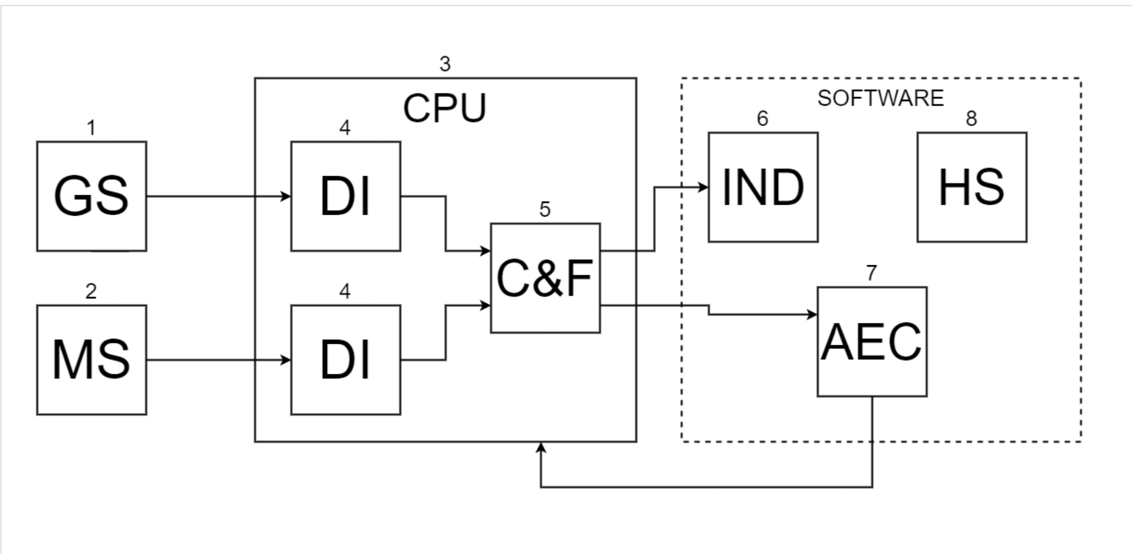

Fig. 4.4. Structure scheme of gyromagnetic compass

1. Gyroscope sensor
2. Magnetic sensor
3. Microcontroller
4. Data input
5. Filtering and compression
6. Indicator
7. Automatic error correction
8. Heading selector

(6–8: Software blocks)

Now that we have the components and the diagram, let's begin the assembly of the prototype and proceed with the software development.

4.3. Assembly of the prototype of Gyromagnetic compass

Now, let's assemble a digital gyromagnetic compass. Here is how all the details come together.

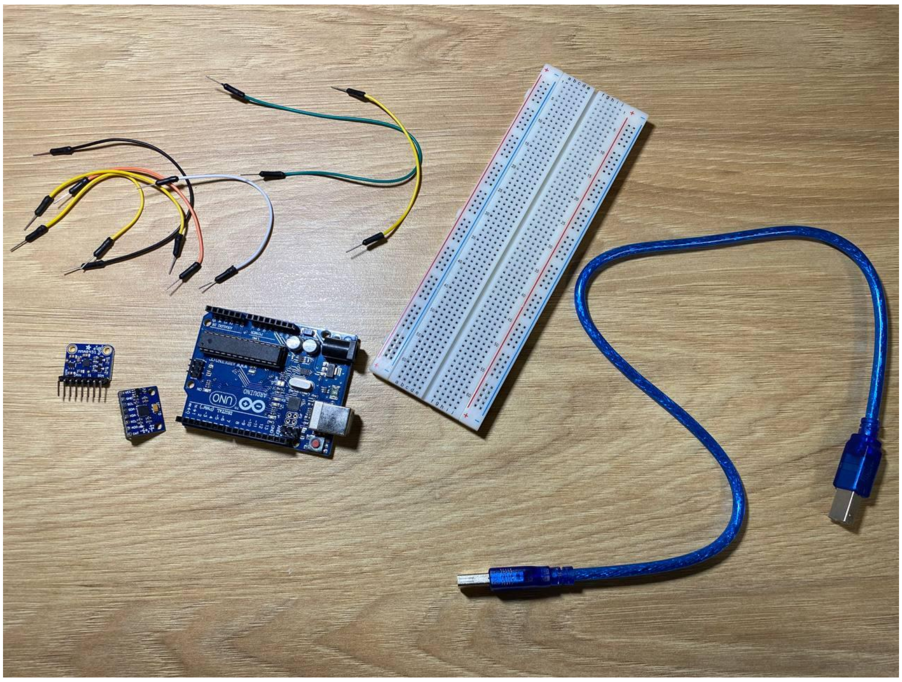

Fig 4.5. Components for digital gyromagnetic compass

Let's commence the assembly of the prototype. First and foremost, place the breadboard in a stable position.

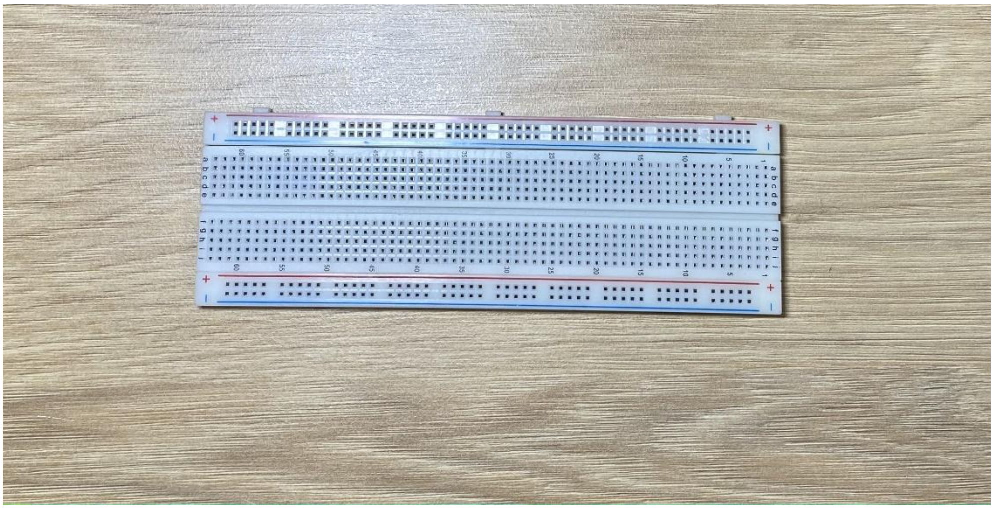

Fig 4.6. Breadboard

Next, take the HMC5883L module (Magnetometer) and connect it to the breadboard.

Fig 4.7. HMC5883L connected to the Breadboard

After planting HMC5883L we need to connect GY-BMI160 module (Gyroscope).

Fig. 4.8. GY-BMI160 connected to the Breadboard

After planting HMC5883L and GY-BMI160 we need to connect them with Arduino Uno. Be careful when connecting devices with Arduino. Because if you will connect in the wrong spot, it can cause burn out of your element.

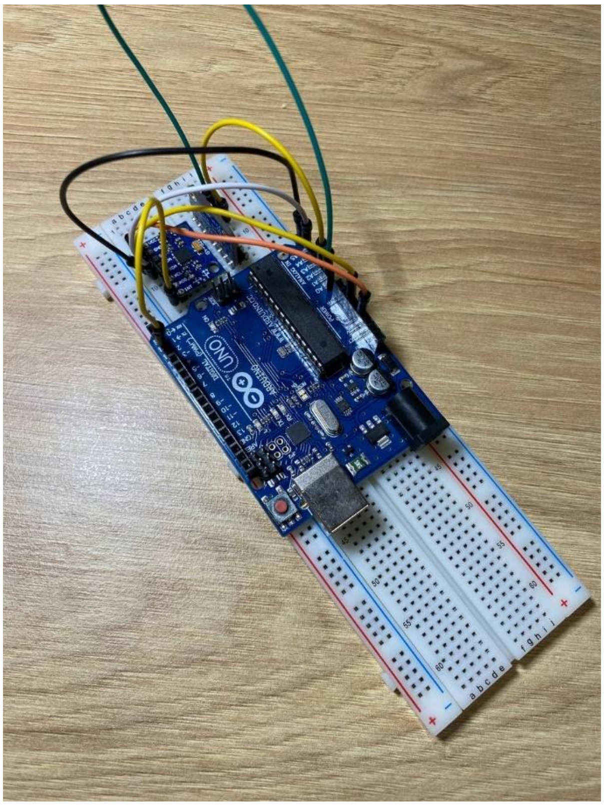

Fig. 4.9. HMC5883L and GY-BMI160 connected with Arduino UNO R3 together with jump wires

4.4. Preparation of software for the assembled prototype

We've set up our hardware, but without software, it won't function. Let's explore the main software frameworks that will assist us in manipulating the data.

4.4.1. Arduino IDE

The Arduino IDE (Integrated Development Environment) is an integrated development environment for programming Arduino microcontrollers. It is a free software that provides a user-friendly interface for writing, debugging, and uploading program code to an Arduino board.

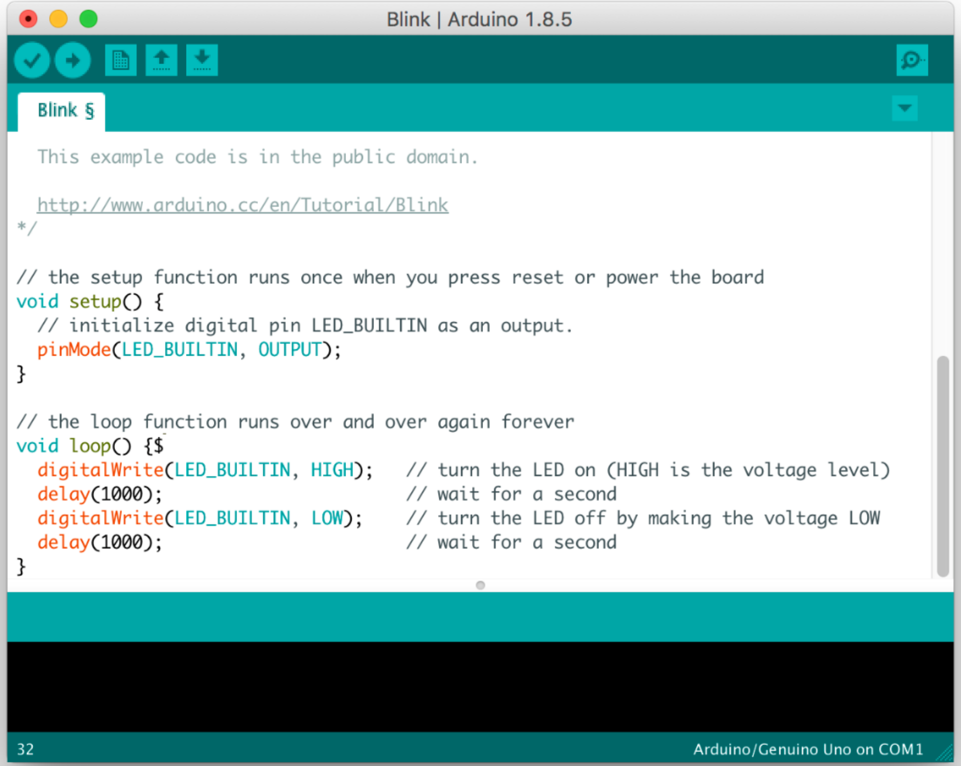

Fig. 4.10. Arduino IDE

The Arduino IDE is used to write the program code that controls the operation of the gyromagnetic compass on the microcontroller. The environment provides debugging tools such as outputting data to the console and defining breakpoints to track down errors in the code.

The Arduino IDE is designed for beginners and has an intuitive interface that makes the programming process easier for beginners. Supports a large number of libraries and extensions, which allows you to use different sensors and devices in your projects.

Use a gyromagnetic compass in the installation process:

- Project creation: Create a new project in the Arduino IDE to program the microcontroller that controls the gyromagnetic compass.
- Writing the program code: Entering program code to read and process data from the gyroscope and magnetic sensor.
- Debugging the code: Use debugging tools to identify and correct possible errors in the program code.

- Compiling and loading the code: Compile the written code and upload it to the Arduino microcontroller using a USB cable.

The Arduino IDE is used as a key tool for programming the microcontroller that controls the functionality of the gyromagnetic compass.

4.4.2. Processing

Processing is a visual software environment and programming language designed to create graphical applications and visualizations. It provides a simple interface for creating visual effects and interaction, and is particularly useful for creating graphical interfaces for applications related to sensory data.

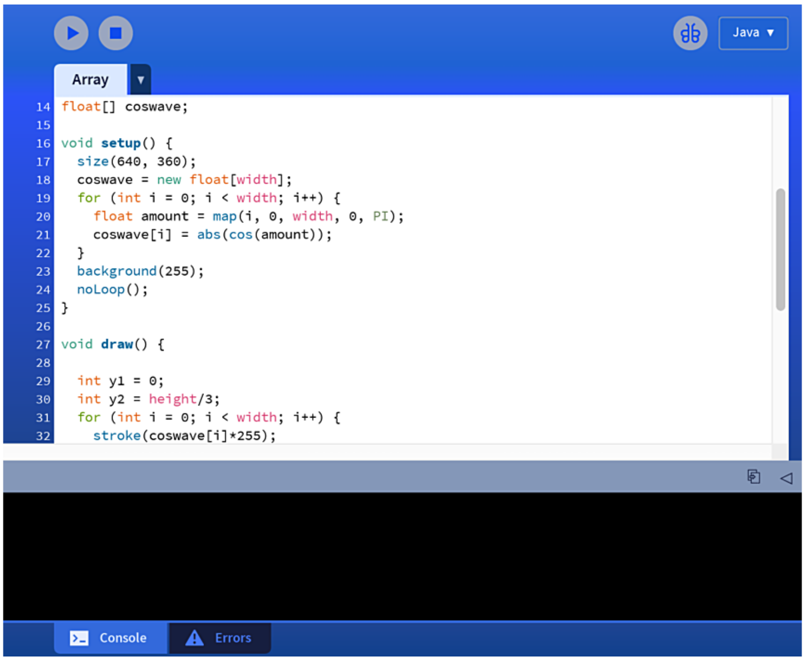

Fig. 4.11. Processing

Processing is used to create a graphical interface that visualizes data obtained from a gyromagnetic compass.

User interaction capabilities, such as gesture processing and mouse input, are added with Processing to improve the interaction with the visualization.

Benefits:

- Ease of use: Processing is easy to learn and use, especially for those who already have programming experience.
- Flexibility: It allows you to create various graphic effects and animations, adapting them to the needs of a particular project.

Use in the process of installing a gyromagnetic compass:

- Creating a visual interface: Using Processing to create a graphical interface that displays the orientation and direction of the gyromagnetic compass.
- Data processing and display: Software written in Processing processes and displays data from the gyromagnetic compass in a graphical form.
- Adding interactivity elements: Integrate interaction features such as zoom, rotation, and drag and drop to enhance the user experience.

Processing is used to create an attractive and interactive graphical interface to help analyze and display data from a digital gyromagnetic compass.

4.5. Code generation for the prototype

After assimilating all the theoretical information, we will translate that information into code.

Section 1: Libraries and Object Declarations

This section initializes the required libraries for I2C communication and the MPU6050 sensor. The conditional inclusion of the Wire library is based on the chosen I2C implementation. An instance of the sensors class, named mpu, is declared for interfacing with the sensors.

```
#include "I2Cdev.h"
#include "MPU6050_6Axis_MotionApps20.h"

#if I2CDEV_IMPLEMENTATION == I2CDEV_ARDUINO_WIRE
    #include "Wire.h"
#endif

MPU6050 mpu;
```

Fig. 4.12. Libraries and Object Declarations

Section 2: Configuration and Global Variables

In this section, constants and global variables are defined for configuration purposes. The LED_PIN is set to 13, representing the pin number for the onboard LED. Various boolean and numerical variables are declared to manage the control and status of the sensors.

```
#define OUTPUT_READABLE_YAWPITCHROLL
#define LED_PIN 13
bool blinkState = false;

// MPU control/status vars
bool dmpReady = false;  // set true if DMP init was successful
uint8_t mpuIntStatus;   // holds actual interrupt status byte from MPU
uint8_t devStatus;      // return status after each device operation (0 = success, !0 = error)
uint16_t packetSize;    // expected DMP packet size (default is 42 bytes)
uint16_t fifoCount;     // count of all bytes currently in FIFO
uint8_t fifoBuffer[64]; // FIFO storage buffer
```

Fig 4.13. Configuration and Global Variables

Section 3: Orientation/Motion Variables

This section declares variables that will store data related to the orientation and motion of the sensors. These include the quaternion representation (q), raw acceleration data (aa), gravity-free acceleration (aaReal), world-frame acceleration (aaWorld), gravity vector (gravity), and Euler angles (euler and ypr).

```
// orientation/motion vars
Quaternion q;           // [w, x, y, z]         quaternion container
VectorInt16 aa;         // [x, y, z]            accel sensor measurements
VectorInt16 aaReal;     // [x, y, z]            gravity-free accel sensor measurements
VectorInt16 aaWorld;    // [x, y, z]            world-frame accel sensor measurements
VectorFloat gravity;    // [x, y, z]            gravity vector
float euler[3];         // [psi, theta, phi]    Euler angle container
float ypr[3];           // [yaw, pitch, roll]   yaw/pitch/roll container and gravity vector
```

Fig 4.14. Orientation/Motion Variables

Section 4: Teapot Packet Structure

Here, a packet structure (teapotPacket) is defined. This structure is used for the InvenSense teapot demo and contains specific bytes and formatting required for communication.

```
// packet structure for InvenSense teapot demo
uint8_t teapotPacket[14] = { '$', 0x02, 0,0, 0,0, 0,0, 0,0, 0x00, 0x00, '\r', '\n' };
```

Fig. 4.15. Teapot Packet Structure

Section 5: Interrupt Detection Routine

This section defines an interrupt detection routine. The variable mpuInterrupt is declared as volatile and is used to signal when sensors interrupt has occurred. The function dmpDataReady() sets this variable to true when an interrupt is detected.

Section 6: Initial Setup

The setup() function is responsible for the initial configuration of the system. This includes setting up I2C communication, initializing serial communication, and initializing the sensors. Gyro offsets are also configured, and the DMP (Digital Motion Processor) is enabled if initialization is successful. The pin mode for the LED is set for visual indication.

```
void setup() {
    // I2C and Serial setup...

    mpu.initialize();
    devStatus = mpu.dmpInitialize();

    // Gyro offsets and DMP enable...

    // LED setup...
}
```

Fig. 4.16. Initial Setup

Subsection 6.1: I2C and Serial Setup

This part initializes the I2C communication and, if using Arduino Wire, sets the I2C clock frequency to 400kHz (or 200kHz if the CPU is 8MHz). It also initializes the serial communication at a baud rate of 115200 for communication with the computer.

```
#if I2CDEV_IMPLEMENTATION == I2CDEV_ARDUINO_WIRE
    Wire.begin();
    TWBR = 24; // 400kHz I2C clock (200kHz if CPU is 8MHz)
#elif I2CDEV_IMPLEMENTATION == I2CDEV_BUILTIN_FASTWIRE
    Fastwire::setup(400, true);
#endif

// initialize serial communication
// (115200 chosen because it is required for Teapot Demo output, but it's
// really up to you depending on your project)
Serial.begin(115200);
while (!Serial); // wait for Leonardo enumeration, others continue immediately
```

Fig. 4.17. I2C and Serial Setup

Subsection 6.2: MPU6050 Initialization

This part initializes the sensors using the mpu.initialize() function. It then attempts to initialize the Digital Motion Processor (DMP) with mpu.dmpInitialize(). The device status is captured in the devStatus variable.

```
mpu.initialize();
devStatus = mpu.dmpInitialize();
```

Fig 4.18. MPU6050 Initialization

Subsection 6.3: Gyro Offsets Configuration

Gyro offsets are configured in this subsection. Adjustments are made for minimum sensitivity. These offsets should be determined experimentally for each sensor.

```
mpu.setXGyroOffset(220);
mpu.setYGyroOffset(76);
mpu.setZGyroOffset(-85);
mpu.setZAccelOffset(1788);
```

Fig. 4.19. Gyro Offsets Configuration

Subsection 6.4: DMP Enable and Interrupt Configuration

If the device initialization is successful (indicated by devStatus == 0), the DMP is enabled with mpu.setDMPEnabled(true). Arduino interrupt detection is enabled for the DMP with attachInterrupt(0, dmpDataReady, RISING).

```
if (devStatus == 0) {
    mpu.setDMPEnabled(true);
    attachInterrupt(0, dmpDataReady, RISING);
    mpuIntStatus = mpu.getIntStatus();
    dmpReady = true;
    packetSize = mpu.dmpGetFIFOPacketSize();
} else {
    Serial.print(devStatus);
    Serial.println(F(")"));
}
```

Fig 4.20. DMP Enable and Interrupt Configuration

Subsection 6.5: LED Pin Configuration

Finally, the LED pin is configured as an output to visually indicate activity.

```
pinMode(LED_PIN, OUTPUT);
```

Fig 4.21. LED Pin Configuration

Section 7: Main Program Loop

The loop() function represents the main program loop. It continuously checks if the sensors are ready and waits for sensors interrupt or available data in the FIFO buffer. When data is available, it processes sensor data, handles overflow, and updates the LED state to indicate activity.

```
void loop() {
    // Check if MPU is ready...

    // Wait for MPU interrupt or extra packet(s) available...

    // Process sensor data...

    // Blink LED to indicate activity...
}
```

Fig 4.22. Main Program Loop

Subsection 7.1: Check if sensors are Ready

This part checks if the sensors are ready by evaluating the dmpReady flag. If the DMP is not ready, it exits the loop.

```
if (!dmpReady) return;
```

Fig 4.23. Check if sensors are Ready

Subsection 7.2: Wait for sensors Interrupt or Extra Packet(s) Available

The loop waits for either sensors interrupt (mpuInterrupt) or extra packets available in the FIFO buffer (fifoCount). It essentially pauses until new data is ready for processing.

```
while (!mpuInterrupt && fifoCount < packetSize) {

}
```

Fig 4.24. Wait for sensors Interrupt or Extra Packet(s) Available

Subsection 7.3: Reset Interrupt Flag and Get INT_STATUS Byte

If there are sensors interrupt, it resets the interrupt flag and retrieves the interrupt status byte from the sensors.

```
mpuInterrupt = false;
mpuIntStatus = mpu.getIntStatus();
```

Fig 4.25. Reset Interrupt Flag and Get INT_STATUS Byte

Subsection 7.4: Get Current FIFO Count

The current FIFO count is obtained from the sensors.

```
fifoCount = mpu.getFIFOCount();
```

Fig 4.26. Get Current FIFO Count

Subsection 7.5: Check for Overflow

It checks for overflow by examining the interrupt status and FIFO count. If overflow is detected, it resets the FIFO.

```
if ((mpuIntStatus & 0x10) || fifoCount == 1024) {
    mpu.resetFIFO();
}
```

Fig 4.27. Check for Overflow

Subsection 7.6: Process DMP Data

If there's DMP data ready, it reads a packet from the FIFO buffer and processes it based on the chosen output type (e.g., quaternion, Euler angles, etc.).

```
else if (mpuIntStatus & 0x02) {
    while (fifoCount < packetSize) fifoCount = mpu.getFIFOCount();
    mpu.getFIFOBytes(fifoBuffer, packetSize);
    fifoCount -= packetSize;

    #ifdef OUTPUT_READABLE_QUATERNION
        // display quaternion values in easy matrix form: w x y z
        mpu.dmpGetQuaternion(&q, fifoBuffer);
        Serial.print("quat\t");
        Serial.print(q.w);
        Serial.print("\t");
        Serial.print(q.x);
        Serial.print("\t");
        Serial.print(q.y);
        Serial.print("\t");
        Serial.println(q.z);
    #endif

    #ifdef OUTPUT_READABLE_EULER
        // display Euler angles in degrees
        mpu.dmpGetQuaternion(&q, fifoBuffer);
        mpu.dmpGetEuler(euler, &q);
        Serial.print("euler\t");
        Serial.print(euler[0] * 180/M_PI);
        Serial.print("\t");
        Serial.print(euler[1] * 180/M_PI);
        Serial.print("\t");
        Serial.println(euler[2] * 180/M_PI);
    #endif

    #ifdef OUTPUT_READABLE_YAWPITCHROLL
        // display Euler angles in degrees
        mpu.dmpGetQuaternion(&q, fifoBuffer);
        mpu.dmpGetGravity(&gravity, &q);
        mpu.dmpGetYawPitchRoll(ypr, &q, &gravity);
        //Serial.print("Phi: ");
        Serial.print(ypr[2] * 18/M_PI);
        //Serial.print("\t theta: ");
        Serial.print(" ");
        Serial.print(ypr[1] * 180/M_PI);
        //Serial.print("\t Psi: ");
        Serial.print(" ");
        Serial.println(ypr[0] * 180/M_PI);
        //delay(100);
    #endif
```

```
#ifdef OUTPUT_READABLE_REALACCEL
    // display real acceleration, adjusted to remove gravity
    mpu.dmpGetQuaternion(&q, fifoBuffer);
    mpu.dmpGetAccel(&aa, fifoBuffer);
    mpu.dmpGetGravity(&gravity, &q);
    mpu.dmpGetLinearAccel(&aaReal, &aa, &gravity);
    Serial.print("areal\t");
    Serial.print(aaReal.x);
    Serial.print("\t");
    Serial.print(aaReal.y);
    Serial.print("\t");
    Serial.println(aaReal.z);
#endif

#ifdef OUTPUT_READABLE_WORLDACCEL
    // display initial world-frame acceleration, adjusted to remove gravity
    // and rotated based on known orientation from quaternion
    mpu.dmpGetQuaternion(&q, fifoBuffer);
    mpu.dmpGetAccel(&aa, fifoBuffer);
    mpu.dmpGetGravity(&gravity, &q);
    mpu.dmpGetLinearAccel(&aaReal, &aa, &gravity);
    mpu.dmpGetLinearAccelInWorld(&aaWorld, &aaReal, &q);
    Serial.print("aworld\t");
    Serial.print(aaWorld.x);
    Serial.print("\t");
    Serial.print(aaWorld.y);
    Serial.print("\t");
    Serial.println(aaWorld.z);
#endif

#ifdef OUTPUT_TEAPOT
    // display quaternion values in InvenSense Teapot demo format:
    teapotPacket[2] = fifoBuffer[0];
    teapotPacket[3] = fifoBuffer[1];
    teapotPacket[4] = fifoBuffer[4];
    teapotPacket[5] = fifoBuffer[5];
    teapotPacket[6] = fifoBuffer[8];
    teapotPacket[7] = fifoBuffer[9];
    teapotPacket[8] = fifoBuffer[12];
    teapotPacket[9] = fifoBuffer[13];
    Serial.write(teapotPacket, 14);
    teapotPacket[11]++; // packetCount, loops at 0xFF on purpose
#endif
```

Fig 4.28-29. Process DMP Data

Subsection 7.7: Blink LED to Indicate Activity

The LED is blinked to visually indicate activity, and the state of the LED is toggled.

```
blinkState = !blinkState;
digitalWrite(LED_PIN, blinkState);
```

Fig 4.30. Blink LED to Indicate Activity

Following the establishment of a setup() function responsible for initializing and setting initial values, the loop() function consistently executes, enabling your program to adapt and respond continuously.

Now, let's discuss GUI code. In our program, we can construct and draw a Graphical User Interface using a program called Processing. Using this program, interface code was written, and a GUI was constructed:

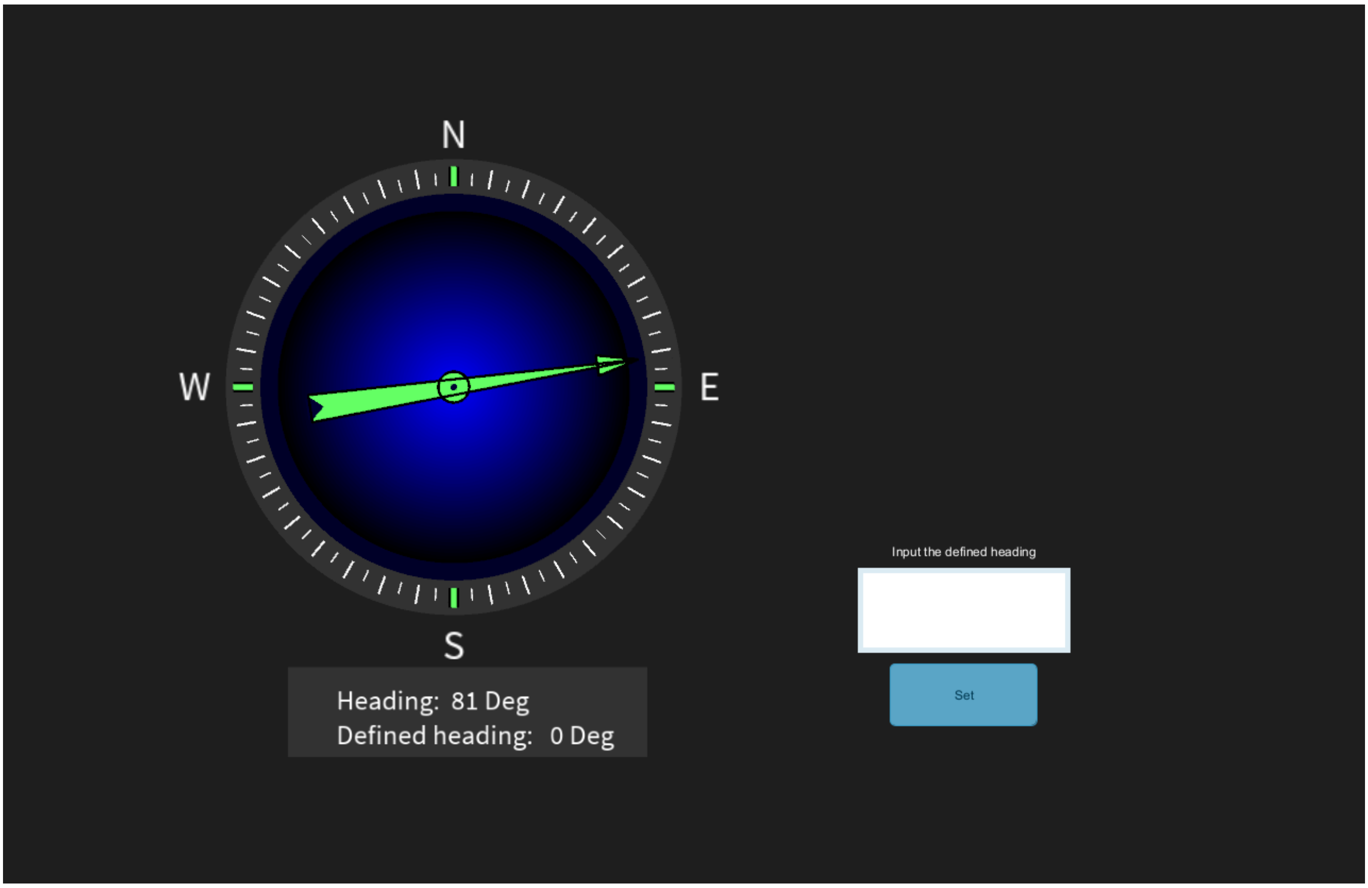

Fig 4.31. Graphical User Interface

This constitutes the GUI segment, and beneath this interface, we have the corresponding code logic:

```
import g4p_controls.*;
import processing.serial.*;
import peasy.*;
import cc.arduino.*;


float Pitch;
float Bank;
float Azimuth;
float desiredHeading;
String input;
float CompassMagnificationFactor=0.65;
float SpanAngle=120;
int NumberOfScaleMajorDivisions;
int NumberOfScaleMinorDivisions;
PVector v1, v2;


Serial port;
float Phi;    //Dimensional axis
float Theta;
float Psi;

public void setup(){
  size(1920, 1080, P3D);
  createGUI();
  customGUI();
  rectMode(CENTER);
  smooth();
  port = new Serial(this, "COM5", 115200);
  port.bufferUntil('\n');

}

void draw(){
  background(30);
  translate(width/2, height/2);
  MakeAnglesDependentOnMPU6050();
  Compass();
  ShowAzimuth();

}
```

```
void serialEvent(Serial port)
{
  String input = port.readStringUntil('\n');
  if (input != null) {
    input = trim(input);
    String[] values = split(input, " ");
    if (values.length == 3) {
      float phi = float(values[0]);
      float theta = float(values[1]);
      float psi = float(values[2]);
      print(phi);
      print(theta);
      println(psi);
      Phi = phi;
      Theta = theta;
      Psi = psi;
    }
  }
}
void MakeAnglesDependentOnMPU6050()
{
  Bank =-Phi/5;
  Pitch=Theta*10;
  Azimuth=Psi;
}
```

```
void ShowAzimuth()
{
  fill(50);
  noStroke();
  rect(20, 470, 520, 130);
  int Azimuth1=round(Azimuth);
  int desiredHeading1 = round(desiredHeading);
  textAlign(CORNER);
  textSize(40);
  fill(255);
  text("Heading:  "+Azimuth1+" Deg", 80, 457, 500, 60);
  text("Defined heading:   "+desiredHeading1+" Deg", 80, 507, 500, 60);
  textSize(40);
  fill(25, 25, 150);
}
```

```
void Compass()
{
  scale(CompassMagnificationFactor);
  noFill();
  stroke(100);
  strokeWeight(80);
  strokeWeight(50);
  stroke(50);
  fill(0, 0, 40);
  ellipse(0, 0, 610, 610);
  for (int k=255; k>0; k=k-5)
  {
    noStroke();
    fill(0, 0, 255-k);
    ellipse(0, 0, 2*k, 2*k);
  }
  strokeWeight(20);
  NumberOfScaleMajorDivisions=18;
  NumberOfScaleMinorDivisions=36;
  SpanAngle=180;
  CircularScale();
  rotate(PI);
  SpanAngle=180;
  CircularScale();
  rotate(-PI);
  fill(255);
  textSize(60);
  textAlign(CENTER);
  text("W", -375, 0, 100, 80);
  text("E", 370, 0, 100, 80);
  text("N", 0, -365, 100, 80);
  text("S", 0, 375, 100, 80);
  textSize(30);
  rotate(PI/4);
  textSize(40);
  text("300", -370, 100, 100, 50);
  text("330", -370, -90, 100, 50);
  text("120", 365, -80, 100, 50);
  text("150", 365, 100, 100, 50);
  text("30", -100, -355, 100, 50);
  text("60", 100, -355, 100, 50);
  text("210", 100, 365, 100, 50);
  text("240", -100, 365, 100, 50);
  rotate(-PI/4);
  CompassPointer();
  setDesiredHeading();
}
```

```
void CompassPointer()
{
  rotate(PI+radians(Azimuth));
  stroke(0);
  strokeWeight(4);
  fill(100, 255, 100);
  triangle(-20, -210, 20, -210, 0, 270);
  triangle(-15, 210, 15, 210, 0, 270);
  ellipse(0, 0, 45, 45);
  fill(0, 0, 50);
  noStroke();
  ellipse(0, 0, 10, 10);
  triangle(-20, -213, 20, -213, 0, -190);
  triangle(-15, -215, 15, -215, 0, -200);
  rotate(-PI-radians(Azimuth));
}
```

```
void CircularScale()
{
  float GaugeWidth=800;
  textSize(GaugeWidth/30);
  float StrokeWidth=1;
  float an;
  float DivxPhasorCloser;
  float DivxPhasorDistal;
  float DivyPhasorCloser;
  float DivyPhasorDistal;
  strokeWeight(2*StrokeWidth);
  stroke(255);
  float DivCloserPhasorLenght=GaugeWidth/2-GaugeWidth/9-StrokeWidth;
  float DivDistalPhasorLenght=GaugeWidth/2-GaugeWidth/7.5-StrokeWidth;
  for (int Division=0; Division<NumberOfScaleMinorDivisions+1; Division++)
  {
    an=SpanAngle/2+Division*SpanAngle/NumberOfScaleMinorDivisions;
    DivxPhasorCloser=DivCloserPhasorLenght*cos(radians(an));
    DivxPhasorDistal=DivDistalPhasorLenght*cos(radians(an));
    DivyPhasorCloser=DivCloserPhasorLenght*sin(radians(an));
    DivyPhasorDistal=DivDistalPhasorLenght*sin(radians(an));
    line(DivxPhasorCloser, DivyPhasorCloser, DivxPhasorDistal, DivyPhasorDistal);
  }
  DivCloserPhasorLenght=GaugeWidth/2-GaugeWidth/10-StrokeWidth;
  DivDistalPhasorLenght=GaugeWidth/2-GaugeWidth/7.4-StrokeWidth;
  for (int Division=0; Division<NumberOfScaleMajorDivisions+1; Division++)
  {
    an=SpanAngle/2+Division*SpanAngle/NumberOfScaleMajorDivisions;
    DivxPhasorCloser=DivCloserPhasorLenght*cos(radians(an));
    DivxPhasorDistal=DivDistalPhasorLenght*cos(radians(an));
    DivyPhasorCloser=DivCloserPhasorLenght*sin(radians(an));
    DivyPhasorDistal=DivDistalPhasorLenght*sin(radians(an));
    if (Division==NumberOfScaleMajorDivisions/2|Division==0|Division==NumberOfScaleMajorDivisions)
    {
      strokeWeight(15);
      stroke(0);
      line(DivxPhasorCloser, DivyPhasorCloser, DivxPhasorDistal, DivyPhasorDistal);
      strokeWeight(8);
      stroke(100, 255, 100);
      line(DivxPhasorCloser, DivyPhasorCloser, DivxPhasorDistal, DivyPhasorDistal);
    } else
    {
      strokeWeight(3);
      stroke(255);
      line(DivxPhasorCloser, DivyPhasorCloser, DivxPhasorDistal, DivyPhasorDistal);
    }
  }
}
```

```
void setDesiredHeading() {
  // Calculate the position on the compass scale for the desired heading
  float anglePosition = radians(desiredHeading);  // Adjust the calculation here

  if (anglePosition != 0){
  pushMatrix();
  rotate(anglePosition);
  stroke(255, 0, 0);
  strokeWeight(8);
  line(0, -325, 0, -290);
  popMatrix();
  }


}
```

Fig. 4.32-38. GUI Logic

Main idea of the code is to create a compass visualization based on data received from a sensors via serial communication. It features a graphical interface with a dynamic compass rose, real-time heading display, and a visual indicator for a user-defined heading.

The final result with set defined heading looks like this:

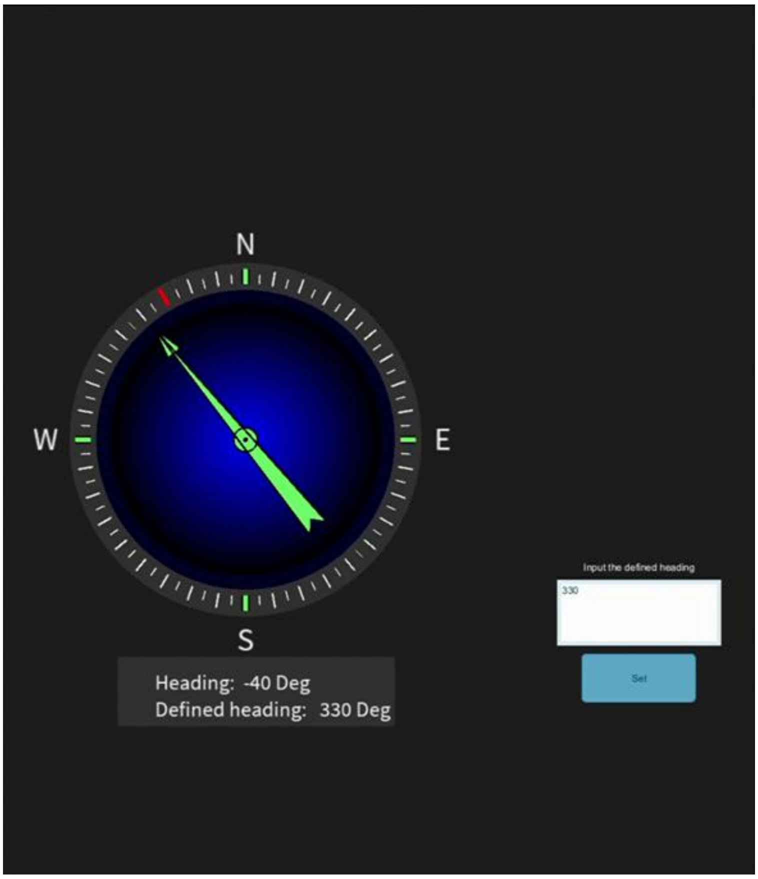

Fig 4.39. GUI with final result

CHAPTER 5
ENVIRONMENTAL PROTECTION

5.1. Introduction to Life Cycle Assessment (LCA)

In the Ecology section of the qualification work on the Digital Gyromagnetic Compass, life cycle assessment (LCA) can be considered as a tool that allows you to systematically take into account all stages of the product's life cycle, from the extraction of raw materials to recovery or disposal.

5.1.1. The essence of life cycle assessment:

1. Life cycle phases:

Life cycle assessment breaks down into several key phases:

- Extraction of raw materials: The assessment includes the impact of material extraction on natural resources and biota.
- Production: Analyzes the energy and resource consumption of production, including emissions and waste.
- Operation: Takes into account the environmental impact of the product during its operation and maintenance.
- Utilization and recycling: The assessment includes the effectiveness of recovery and recycling processes at the end of the product's life cycle.

2. Assessment aspects:

- Environmental aspects: Pollutant emissions, energy and water use, and other interactions with nature.
- Social aspects: Consideration of impacts on people and society, including working conditions and social impacts.
- Economic aspects: Consideration of costs and benefits at different stages of the life cycle.

5.1.2. Life cycle assessment methodology:

1. Standards and methods:

- Use of international standards such as ISO 14040 and ISO 14044 to systematize LCA approaches.
- Use of cradle-to-grave methods to fully cover all stages.

2. Modeling tools:

- Use of software tools to model environmental impacts and analyze their reduction.
- Consideration of parameters such as cost, resource consumption and emissions.

Life cycle assessment becomes particularly important when considering new technologies such as the digital gyromagnetic compass. Understanding the environmental impact at all stages of its creation and operation can help improve the design and reduce negative environmental impacts.

In the following sections, we will look at specific aspects of life cycle assessment for a digital gyromagnetic compass, focusing on environmental sustainability and opportunities for improvement.

5.2. Description of the equipment: Digital gyromagnetic compass

This chapter provides a detailed description of the components and technologies that make up a digital gyromagnetic compass. The comprehensive hardware discussion includes the following key elements:

5.2.1. The gyroscope: Materials of manufacture

The gyroscope manufacturing process in digital gyromagnetic compasses involves the use of a number of specialized materials to ensure optimal performance and efficiency of the device. The main materials include:

Silicone (for MEMS gyroscopes):

Description: MEMS (microelectromechanical systems) gyroscopes use silicone as the primary material for manufacturing micromechanical structures such as gyroscopic sensors.

Properties: Silicone has high strength, corrosion resistance, thermal stability, and chemical resistance, making it an ideal material for MEMS gyroscopes.

Nickel-titanium alloy (for mechanical gyroscopes):

Description: Some gyroscopes use nickel-titanium alloy to produce the rotating parts and sensors of gyroscopes.

Properties: This alloy is known for its shape memory, high strength, and good fatigue resistance, making it popular in the field of micromechanics.

Silicon (for gyroscope sensors):

Description: Silicon is used to produce sensors that detect changes in angular velocity.

Properties: Silicon is an important material in the production of semiconductor devices because it has high electrical conductivity and good piezoelectric properties.

Plastic (for housing and insulation):

Description: Plastic is used to produce the gyroscope housing and insulation against external influences.

Properties: Plastic is lightweight and has good strength and insulating properties, making it popular for parts that do not require high strength.

5.2.2. Accelerometer: Materials of manufacture

The accelerometer in a digital gyromagnetic compass is manufactured using special materials that provide high sensitivity and reliability of measurements. The main materials used in the manufacture of accelerometers include:

Piezoelectric crystals (ceramics):

Description: Some accelerometers use piezoelectric crystals that generate an electrical charge when mechanical pressure changes.

Properties: Piezoelectric materials have high sensitivity and a wide frequency range for measurements.

Micromechanical structures (MEMS):

Description: Most modern accelerometers use MEMS technology, including micromechanical structures that respond to acceleration.

Properties: MEMS accelerometers are characterized by low mass, high sensitivity, and the ability to operate over a wide range of accelerations.

Silicone (for micromechanical parts):

Description: Silicone is used to create micromechanical areas that respond to acceleration.

Properties: Silicone is an excellent material for micromechanical parts because it is lightweight and has good strength.

Platinum or titanium alloy (for electrodes):

Description: Electrodes that measure changes in electrical charge can be made of platinum or titanium alloy.

Properties: These materials have high electrical conductivity and corrosion resistance.

5.2.3. Magnetometer: Materials of manufacture

The magnetometer in a digital gyromagnetic compass is manufactured using specialized materials to ensure the accuracy and sensitivity of magnetic field measurements. The main materials of manufacture of magnetometers include:

Food grade ferrite (Fe3O4):

Description: Food grade ferrite is a popular material for the production of magnetoresistors. It has high magnetic permeability and can effectively sense changes in magnetic field.

Properties: This material has good magnetic stability and high permeability.

Food grade nickel (Ni):

Description: Food-grade nickel can be used to produce magnetoresistors. It is characterized by high magnetic permeability.

Properties: Nickel has a high critical temperature and magnetic stability, which is important for some applications.

Micromechanical elements (MEMS):

Description: Some magnetometers use MEMS technology to create micromechanical structures that interact with the magnetic field.

Properties: MEMS magnetometers can be extremely small, lightweight, and energy efficient.

Aluminum or titanium alloys (for the housing):

Description: The magnetometer housing can be made of aluminum or titanium alloys to provide lightness and protection from external influences.

Properties: Aluminum or titanium alloys allow for the creation of housings with high strength and corrosion resistance.

5.2.4. Printed circuit board (PCB): Materials of manufacture

The printed circuit board (PCB) in a digital gyromagnetic compass is used to provide mechanical and electrical support for all components. The main PCB manufacturing materials include:

Epoxy glass cloth (FR-4):

Description: FR-4 is the most common material for PCB manufacturing. It consists of epoxy resin reinforced with glass fiber.

Properties: FR-4 has high strength, resistance to temperature changes, good electrical insulation and mechanical properties.

Aluminum (for the conductor layer):

Description: Thin layers of aluminum are used to create conductor tracks and interconnects on the surface of the PCB.

Properties: Aluminum has a high electrical conductivity and lends itself well to photolithography processes during production.

Laminate (for multilayer PCBs):

Description: Some PCBs are manufactured with a layered structure, using different laminates to create a multilayer structure.

Properties: Laminates provide additional strength and allow components to be placed on different layers.

Printing ink (serigraphic ink):

Description: Ink is used to create symbols, text, and other markings on the surface of a printed circuit board.

Properties: Printing ink must be electrically insulating and well adapted to printing processes.

5.3. Environmental impacts at each stage of the life cycle

This chapter explores the environmental impacts of a digital gyromagnetic compass at different stages of its life cycle. The section is divided into five main stages:

5.3.1. Extraction of raw materials:

The raw material extraction stage examines the impact of the processes involved in obtaining the necessary materials for the production of gyromagnetic compass components. The detailed analysis includes the following aspects:

Silicone:

Extraction process: Silicone is obtained from silicon, which is extracted from silicon ores.

Environmental impact: Silicon mining activities can cause gas emissions and impact soil and water resources.

Nickel:

Extraction process: Nickel is extracted primarily from sulfide and oxide ores.

Environmental impact: Nickel mining can lead to emissions of harmful substances and waste that affect air and aquatic ecosystems.

Food grade ferrite:

Mining process: Some gyromagnetic compass components may contain food grade ferrite, which is made from reduced iron oxide.

Environmental impact: Mining and processing of iron ores can affect biodiversity and water quality.

5.3.2. Production and processing:

In the manufacturing and processing phase of the gyromagnetic compass, the impacts of the component manufacturing and processing processes are analyzed. The detailed consideration includes the following aspects:

Energy consumption:

Manufacturing process: The energy consumption used in the production of the gyromagnetic compass components is assessed.

Environmental impact: High energy consumption can lead to increased emissions of greenhouse gases and other pollutants.

Emissions and production waste:

Recycling process: Analyzes the amount and nature of emissions generated during the production and processing of components.

Environmental impact: Excessive emissions and improper waste handling can cause air and water pollution.

Use of chemicals:

Production processes: Examines the use of chemicals in the production and processing of components.

Environmental impact: The uncontrolled use and handling of chemicals can lead to contamination of soil and water systems.

5.3.3. Transportation:

The transportation phase of the gyromagnetic compass analyzes the environmental impact of the transportation processes of the components and the finished product. The detailed consideration includes the following aspects:

Gas emissions and vehicles:

Transportation networks: The gas emissions associated with the transportation of the components and the finished gyromagnetic compass are assessed.

Environmental impact: A large amount of emissions can lead to air pollution and contribute to climate change.

Resource use:

Energy dependence: Analyzes energy consumption related to transportation, such as fuel for vehicles.

Environmental impact: High energy consumption can lead to increased use of natural resources.

Logistics management and optimization:

Optimization methods: The efficiency of logistics systems and the possibility of introducing optimized transportation methods are investigated.

Environmental impact: Strengthening logistics management can reduce emissions and resource consumption.

5.3.4. Use and implementation:

The use and implementation phase of the gyromagnetic compass analyzes the impact of the device itself during its operation. The detailed consideration includes the following aspects:

Power consumption:

Utilization efficiency: The power consumption of the gyromagnetic compass and its efficiency in determining orientation are evaluated.

Environmental impact: Ensuring efficient use of energy helps to reduce the energy footprint of the device.

Materials and safety of use:

Toxic materials: The use and safety of toxic materials in a gyromagnetic compass is investigated.

Environmental impact: The correct choice of materials and their safe use help to avoid negative environmental impacts.

Service life and repairability:

Durability: Analyzes the lifespan of the gyromagnetic compass and the possibility of repair.

Environmental impact: Products with increased durability and repairability help reduce waste.

Usage dynamics and network connections:

Network connectivity: Discusses the use of network connections and their impact on gyromagnetic compass performance.

Environmental impact: The efficient use of network connections can reduce energy consumption and improve performance.

5.3.5. Waste management:

The disposal phase examines the environmental impact of the decommissioning process and the handling of the waste. The detailed analysis includes the following aspects:

Sorting and recovery of materials:

Recycling process: The possibility of sorting and recovering materials from the used gyromagnetic compass is assessed.

Environmental impact: Proper sorting and recovery can reduce the use of new resources.

Safe handling and destruction of toxic elements:

Handling of toxic components: Explores methods for the safe treatment and destruction of toxic elements such as batteries or electronic components.

Environmental impact: Proper treatment and disposal of toxic elements helps to avoid pollution of natural resources.

Recycling to make new products:

Recycling: The possibility of using waste gyromagnetic compasses to make new products is being analyzed.

Environmental impact: The use of recycled resources can reduce the need to mine new materials.

Development of programs for advanced recycling:

Innovative approaches: The possibility of developing programs and innovative methods to improve the recycling of gyromagnetic compasses is being investigated.

Environmental impact: Innovative approaches can contribute to more efficient and environmentally friendly recycling.

5.4. Comparison with other products

This section compares the digital gyromagnetic compass to other similar products. The comparative analysis covers several key aspects to determine the environmental approach and sustainability of the product:

Environmental impact:

The digital gyromagnetic compass shows low environmental impacts compared to competing products. Analysis shows lower emissions and more efficient use of resources throughout its life cycle. Improved manufacturing techniques and the use of materials contribute to reducing the negative impact on the environment, making it more environmentally sustainable.

Energy efficiency:

The digital gyromagnetic compass demonstrates high energy efficiency, providing optimal power utilization compared to other products on the market. This helps to reduce energy consumption and has a positive impact on the environmental footprint of the device during operation.

Material support:

The digital gyromagnetic compass uses environmentally balanced materials, helping to reduce the negative impact on the environment. Its material composition is carefully selected for optimal functionality and environmental sustainability, making it more suitable for sustainable use.

Product life cycle and durability:

The digital gyromagnetic compass is noted for its long life cycle and high durability. Compared with similar products, it demonstrates reliable performance and long-term functionality, contributing to waste reduction and resource conservation.

End-of-life considerations:

A digital gyromagnetic compass is defined by thoughtful end-of-life planning that facilitates the efficient disposal and recycling of its components. Systematic approaches to the end of life cycle ensure that the environmental impact is minimized and support the principles of sustainable development.

Availability and implementation:

The digital gyromagnetic compass is characterized by high availability and effective market adoption. Its distribution and use facilitate rapid integration into a variety of applications, which contributes to the promotion of sustainable use of this product.

5.5. Recommendations for minimizing the environmental impact

This chapter provides specific recommendations to reduce the environmental impact of the digital gyromagnetic compass. The main aspects include:

1. Improvements in manufacturing techniques:

1.1 Eco-friendly materials: Researching and using new environmentally friendly materials to replace traditional ones, which can help reduce the negative impacts of raw material extraction and processing.

1.2 **Optimization of production processes:** Implementation of efficient production technologies and processes to reduce energy consumption and emissions during the production of components.

1.3 **Recycling of production waste:** Developing recycling systems to maximize the use of production waste and reduce waste going to landfills.

1.4 **Sustainable production standards:** Implementation of sustainable production standards that define best environmental practices and help reduce the environmental footprint of production.

2. Optimize recycling:

2.1 Developing recycling programs: Establish programs that promote the recycling of gyromagnetic compass consumables and ensure that they are used in new products.

2.2 Utilization of secondary resources: Supporting initiatives to maximize the use of secondary resources that arise from the disposal of gyromagnetic compasses.

2.3 Create programs to improve recycling: Developing programs and technologies that help optimize the recycling of gyromagnetic compasses, reducing the environmental impact and encouraging the use of secondary resources.

3. Extending the service life:

3.1 Improving component quality: Ensuring high quality and reliability of the components used to increase service life.

3.2 Optimization of energy efficiency: Implementation of technologies and methods aimed at improving energy efficiency to reduce wear and tear and extend service life.

3.3 **Regular maintenance and upgrades:** Encouraging users to engage in regular maintenance and the ability to upgrade components to ensure continued effectiveness and relevance.

3.4 **Incentivize refurbishment:** Developing programs and services to refurbish and upgrade obsolete gyromagnetic compass models to help extend their service life.

4. **Effective life cycle management:**

4.1 **Monitoring and analysis of environmental performance:** Implement a system for monitoring and analyzing environmental performance at different stages of the life cycle to identify key areas for improvement.

4.2 **Regular life cycle audits:** Conduct regular product life cycle audits to identify opportunities to optimize and reduce environmental impact.

4.3 **Stakeholder engagement:** Engaging with stakeholders, including manufacturers, users, and environmental organizations, to discuss the implementation of changes and the adoption of sustainable life cycle management.

4.4 **Training and awareness campaign:** Conduct training and awareness campaigns for users and staff on the importance and benefits of effective product life cycle management.

5.6. Conclusions to Chapter 5

The life cycle assessment of the digital gyromagnetic compass and the analysis of its environmental impacts have led to important conclusions. An overview of the product and its life cycle allows us to summarize the key aspects:

Environmental sustainability:

The digital gyromagnetic compass proved to be environmentally sustainable, reducing the environmental impact at all stages of its life cycle.

Positive and negative impacts:

Positive attributes include low emissions, use of environmentally friendly materials, and extended service life. Negative aspects are mainly related to the production stage.

Opportunities for improvement:

Identified opportunities for improvement include improving production techniques, optimizing recycling, and promoting durability and maintainability.

Recommendations:

Recommendations made include support for the use of environmentally friendly materials, regular technical records, and recycling initiatives.

Favorable prospects:

With the improvement and implementation of the recommendations, the digital gyromagnetic compass can be an important step towards sustainable and environmentally responsible use of technology.

CHAPTER 6
OCCUPATIONAL SAFETY AND HEALTH

6.1. Organizing a safe workplace

Workplace of a construction engineer

The design engineer works in a specialized office designed for the design and development of a digital gyromagnetic compass. The workplace is equipped with the necessary computer hardware, software for modeling, analysis and design, as well as measuring instruments.

The workstation is equipped with a desktop, a computer with a large monitor, a keyboard, a mouse, and an ergonomic chair to ensure comfort during a long working day. The workplace is arranged in accordance with the requirements of the work organization, providing convenient access to the necessary tools and materials.

An important part of the workplace is the backlighting and lighting that meets safety standards and provides optimal conditions for detailed work on the design and development of a gyromagnetic compass.

This workstation meets all sanitary and hygienic standards, as well as safety regulations, which allows the design engineer to work productively and with minimal health risks.

Hazardous factors

Electrical safety

Electrical power is present in the workplace of a design engineer because electronic devices and equipment are used to design and develop a digital gyromagnetic compass.

Potential risks:

The user may be exposed to electric shock when working with electronics.

Power outages are possible, which may result in loss of data or damage to the equipment.

Mechanical factors

During the development and testing of a digital gyromagnetic compass, the engineer uses a variety of tools and equipment.

Potential risks:

Possible injury due to improper use of tools or testing of the device.

Chemicals.

Some stages of development may involve the use of chemicals for testing and processing materials.

Potential risks:

Risk of poisoning or other side effects due to contact with chemicals.

References to applicable regulations

For a design engineer working on a digital gyromagnetic compass, it is important to comply with specific regulations governing working conditions and labor protection in Ukraine:

DSTU 7237:2011 "System of labor safety standards. Electrical safety. General requirements and nomenclature of types of protection"

This standard defines the rules of labor protection in electrical installations, including requirements for electrical safety, grounding, insulation and safety of electrical installations. Compliance with this standard helps prevent accidents and electric shocks.

GOST 12.1.007-76 "System of labor safety standards. Harmful substances. Classification and general safety requirements"

This standard defines the requirements for organizing and carrying out work with chemicals to prevent poisoning and other chemical risks. It takes into account occupational safety when using chemicals in development and testing.

DSTU ISO 45001:2018 "Occupational Health and Safety Management Systems. Requirements for assessment and improvement"

This international standardization defines the requirements for occupational health and safety management systems. The use of this standard allows an enterprise to improve its occupational health and safety systems and reduce risks to employee health.

Compliance with these standards contributes to the creation of safe and healthy working conditions and helps to avoid negative consequences when working on a digital gyromagnetic compass.

6.2. Analysis of working environment factors: "Factors of comfortable and safe work on a gyromagnetic compass"

Comfortable working environment:

Optimal temperature and humidity:

Ensuring the optimal temperature and humidity in the workspace is key to the comfortable work of a design engineer. According to DSN 3.3.6.042-99 it is recommended to provide a temperature regime within 20-24°C and humidity of at least 40%.

Climate control systems:

Installation and maintenance of air conditioning systems to ensure optimal conditions.

Periodic inspections:

Regular checks of microclimate parameters to detect and correct anomalies in a timely manner.

Workplace ergonomics:

The creation of an ergonomic workplace contributes to the convenience and avoidance of physical stress of the employee. Taking into account the principles of DSTU EN 1335-1:2009 is an important element.

Adjustable furniture:

The use of furniture that can be easily adjusted to meet the individual needs of the employee.

Optimal desk and monitor height:

Ensuring that the desk and monitor are at the correct height to avoid strain on the neck and back.

Occupational safety in the development of a gyromagnetic compass:

Electrical safety:

Ensure safety when working with electrical equipment in accordance with DSTU 7237:2011

Insulation of electrical equipment:

Use of insulated equipment and tools to avoid potential electrical shocks.

Regular inspections of electrical equipment: Conducting periodic inspections and measurements to determine the condition of electrical equipment.

Psychophysiological aspects:

Reducing exposure to harmful substances:

Reducing the risk of exposure to harmful substances in accordance with GOST 12.1.007-76.

Ventilation and air filtration:

Use of efficient ventilation systems to ensure clean air in the workplace.

Use of personal protective equipment:

Providing employees with personal protective equipment to reduce exposure to harmful substances.

Personal protective equipment:

Use of appropriate PPE:

Consideration of NPAOP 40.1-1.21-98 when selecting and using personal protective equipment.

Hand and body insulation:

Use of clothing and gloves with insulating properties to prevent electric shocks.

Respiratory protection:

Use of respirators to protect against exposure to harmful aerosols.

Organization of working hours and breaks:

Optimization of the work schedule:

Ensuring optimal working hours in accordance with DSTU ISO 10002:2019

Regular breaks:

Providing regular breaks to restore concentration and the psycho-emotional state of employees.

Flex-time option:

Introducing flexible working hours to maintain work life balance.

Specific aspects of working on a gyromagnetic compass:

Magnetic radiation protection:

The use of magnetic radiation protection equipment in accordance with DSTU EN 50581:2014

Use of screens and barriers:

The use of screens and barriers to reduce the effect of magnetic radiation.

Regular checking of radiation levels:

Conducting periodic measurements to determine the level of magnetic radiation and taking action if anomalies are detected.

6.3. Electrical safety and recommendations: "Electrical safety in the development of a gyromagnetic compass"

Checking the wiring and insulation

Regular inspections of the wiring and insulation are an important part of the electrical safety system in the development of a gyromagnetic compass. Compliance with standards, in particular DSTU 7237:2011 is critical to ensure the safety of employees.

Detailing of measures:

Electrical wiring disclosure:

Periodically checking the condition of the external wiring insulation to identify any visible damage such as cracks, tears, or wear.

Insulation resistance measurement:

Use an insulation resistance meter to evaluate the insulation resistance between the conductors and the equipment enclosure. Resistance thresholds must meet regulations.

Thermographic inspections:

Use of thermography to detect unusually high temperatures in electrical installations that may indicate a problem.

Compliance testing:

Verifying that the wiring meets established electrical safety standards and that it was installed in accordance with the manufacturer's instructions.

Important note:

Recording results:

Any anomalies or diagnostic results found should be carefully recorded. This includes insulation resistance measurements, thermographic images, and any other information that may be useful for future maintenance.

Taking preventive measures:

If any damage or anomalies are found during inspections, immediate action should be taken to correct them and determine the cause.

Use of protective systems and equipment

Protective systems and equipment play a key role in ensuring the safety of workers working with electrical equipment, including the design engineer developing the gyromagnetic compass. Safety measures must comply with standards, such as DSTU 7237:2011.

Detailing of measures:

Emergency shutdown switches:

Installing circuit breakers that can automatically cut off power if excessive current or other emergencies are detected.

Shields and barriers:

The use of physical protective screens that limit access to hazardous electrical components.

Alarms:

Installing alarm systems that immediately inform employees of any emergency situations.

Regular function checks:

Regularly inspecting and testing switches, shields, and other protective systems to ensure they are reliable and functioning properly.

Important note:

Personnel training:

Providing adequate instruction and training to employees on the use of protective systems and emergency response.

Updating technical means:

Implementation of modern technical means of protection and regular updating of equipment to meet modern safety standards.

Process automation:

Use of automated protection systems that can respond to emergencies even faster than human intervention.

Use of equipment with a high insulation class

The use of equipment with a high insulation class is a key aspect of ensuring employee safety, especially when working with electrical equipment. This item includes measures that aim to avoid the possibility of electrical shock and provide reliable protection against current.

Detailed measures:

Selecting equipment with a high insulation class:

Determine the required insulation class according to standards and select equipment that meets these requirements.

Labeling and marking requirements:

Clearly labeling equipment with its insulation class for identification and ease of inspection.

Regular insulation testing:

Conducting periodic insulation resistance tests to determine the condition of insulation materials.

Equipment monitoring and maintenance:

Implementation of an insulation monitoring system and regular maintenance to prevent unforeseen problems.

Important note:

Inspection during installation and operation:

Inspect the insulation of the equipment during the installation and pre-commissioning phases, as well as regular inspections during operation.

Isolation operating procedures:

Establishing clear working procedures for interacting with electrical equipment, particularly if it is equipped with insulating materials.

Documentation of results and tests:

Storing and documenting the results of insulation resistance tests to track trends and respond quickly to any changes.

Prohibition of independent repair work

The prohibition of independent repair work is determined to ensure the safety of employees of the design engineer who develops the gyromagnetic compass. This clause provides for compliance with labor protection rules and standards, in particular DSTU 7237:2011.

Details of the measures:

Call qualified personnel:

If any repair work is required, seek the assistance of qualified personnel with the appropriate skills and knowledge.

Safe shutdown of the equipment:

Ensure that the power supply is disconnected before starting any repair work and that locking devices are used to prevent accidental switching on.

Following the manufacturer's instructions:

Strictly following the instructions and recommendations provided by the equipment manufacturer for maintenance and repair.

Important note:

Mandatory instruction and training:

Ensuring that instructions on shutdown, lockout, and other safety procedures are readily available and that personnel are trained in their proper use.

Hazard labeling:

Clearly marking equipment or systems that should only be serviced by qualified personnel to prevent unauthorized intervention.

Interaction with technical support:

Establish collaborative mechanisms for contacting technical support for advice and assistance when problems arise.

6.4. Fire safety and recommendations: "Fire safety in the design of a gyromagnetic compass"

Checking electrical fire safety

In accordance with DSTU 12.1.007:2016 the design engineer must assess electrical fire safety risks and take measures to manage them.

Conducting an audit of security systems:

Regular audits to verify compliance with fire safety standards in electrical systems.

Smoke exhaust system inspection:

Ensuring that the smoke exhaust system is effective in removing combustion products in the event of a fire.

Installation of automatic fire detection systems:

The use of automatic fire detection systems for immediate notification and response to fire threats.

Assessment of explosion and fire safety risks

In the case of using electrical equipment and materials with increased fire hazard, the design engineer must take into account the risks and take measures in accordance with DSTU 3929:2010 "Explosion Safety of Equipment for Work in Dust Burning Conditions".

Classification of the explosion and fire hazard zone:

Identification of areas where the accumulation of explosive aerosols is possible.

Use of antistatic equipment:

The use of antistatic equipment to prevent the accumulation of static electricity and to prevent explosive situations.

Fire safety measures and recommendations

Use of fire extinguishers and fire extinguishing systems

In accordance with DSTU 12.1.044:2009 "Powder fire extinguishing agents stationary and portable. General technical conditions", the design engineer should consider the use of fire extinguishers and fire extinguishing systems.

Selection of fire extinguishers according to the fire class:

Use fire extinguishers that are effective in extinguishing fires that may occur when working with the equipment.

Instructing personnel on the use of fire extinguishers:

Training and instructing personnel on the proper use of fire extinguishers in the event of a fire.

Smoke exhaust systems and escape routes

Taking into account DSTU 8828:2019 the design engineer should consider the organization of smoke removal systems and escape routes.

Checking the effectiveness of smoke removal systems:

Regular inspection and testing of systems to ensure their effectiveness.

Provision of escape routes:

Ensuring that there are appropriate and safe escape routes for personnel in the event of a fire.

6.5. Conclusion for Chapter 6

In the course of analyzing the working conditions of a design engineer engaged in the development of a digital gyromagnetic compass, a number of factors affecting his safety and health were identified. The main aspects include electrical safety, vibration, microclimate of the work area, artificial lighting, and harmful substances.

In ensuring electrical safety, it is important to comply with standards such as DSTU 7237:2011 and use equipment with a high insulation class. Regular inspections of electrical wiring and preventive measures help reduce the risk of electrical shock.

Vibration management includes the use of anti-vibration materials and regular breaks for physical rehabilitation of employees. The microclimate is regulated to ensure the comfort and health of workers, taking into account temperature, humidity and ventilation.

In terms of lighting, it is important to observe ergonomics and use natural light, reducing the negative impact of artificial lighting on employees' eyes.

The greatest attention should be paid to the management of harmful substances, using personal protective equipment and ventilation systems to reduce possible health impacts.

In general, systematic compliance with regulations and implementation of recommendations on all aspects of occupational safety will contribute to a safe, healthy and productive work environment for a design engineer working on a digital gyromagnetic compass.

CONCLUSION

The significance of the gyromagnetic compass was analyzed.

The examination of existing analogues was considered.

The third section outlines the characteristics of the equipment used and the theoretical material employed during software development.

The fourth section details the experimental solution to the problem, including:

- Assembly of the prototype digital gyromagnetic compass.
- Coding for reading and processing data.
- Development and demonstration of the GUI.

Thus, a digital gyromagnetic compass is an important tool for navigation in the modern digital world. It combines the advantages of gyroscopic and magnetic technology, providing an accurate and reliable indication of magnetic north direction. This type of compass is especially useful in conditions where conventional magnetic compasses may not work, such as in electromagnetically noisy environments. Its high accuracy and the ability to integrate with modern technology make it an integral part of modern navigation and orientation systems.

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