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

" ____ " _____2023 р.

КВАЛІФІКАЦІЙНА РОБОТА

(ПОЯСНЮВАЛЬНА ЗАПИСКА)

ВИПУСКНИКА ОСВІТНЬОГО СТУПЕНЯ

"БАКАЛАВР"

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

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

Тема: Інтерфейс користувача системи управління випробувальним комплексом навігаційного обладнання

Виконавець: студент групи КП-404Ба Собко Данило Едуардович

Керівник: Долгоруков С.О.

Нормоконтролер: Філяшкін М.К.

Київ – 2023

MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE

NATIONAL AVIATION UNIVERSITY

Faculty of Aeronavigation, electronics and telecommunication

Department of computer integrated complexes

ADMIT TO DEFENSE

Head of Department

_____ Viktor M. Sineglazov

" ____ " _____2023 y.

QUALIFICATION WORK

(EXPLANATORY NOTE)

EDUCATION DEGREE

"BACHELOR"

Specialty 151 «Automation and Computer-Integrated Technologies»

Training program «Computer-integrated technological processes and production»

Topic: The user interface of the navigation equipment test complex management system

Prepared by: student КП-404Ба group Sobko Danylo Eduardovich

Supervisor: S.O. Dolhorukov

Standard controller: M.K. Filiashkin

Kyiv - 2023

НАЦІОНАЛЬНИЙ АВІАЦІЙНИЙ УНІВЕРСИТЕТ

Факультет аеронавігації, електроніки та телекомунікацій

Кафедра авіаційних комп'ютерно-інтегрованих комплексів

Освітній ступінь: «Бакалавр»

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

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

ЗАТВЕРДЖУЮ

Завідувач кафедри

_____ Віктор СИНЄГЛАЗОВ

" ____ " _____2023 р.

ЗАВДАННЯ

на виконання кваліфікаційної роботи студента

Собко Данила Едуардовича

1. **Тема роботи:** «Інтерфейс користувача системи управління випробувальним комплексом навігаційного обладнання».

2. **Термін виконання роботи:** з 22 травня 2023р. до 14 червня 2023р.

3. **Вихідні дані до роботи:** програмний інтерфейс користувача.

4. **Зміст пояснювальної записки (перелік питань, що підлягають розробці):** Навігаційне обладнання випробувального комплексу та методи розробки інтерфейсу; ідентифікація потрібних функцій для інтерфейсу користувача; огляд характеристик тестового комплексу та процесу тестування; концептуальний дизайн інтерфейсу користувача; реалізація інтерфейсу використовуючи програму LabView.

5. **Перелік обов'язкового графічного матеріалу:** Зображення програмної реалізація інтерфейсу користувача системи управління випробувальним комплексом навігаційного обладнання

APPROVED BY

Head of Department

_____ Viktor M. Sineglazov

" ____ " _____2023 y.

TASK

for the qualification work of student

Sobko Danylo Eduardovich

1. **Topic of the work:** «The user interface of the navigation equipment test complex management system».

2. **Period of work execution:** from May 22, 2023, until June 14, 2023.

3. **Output data:** software user interface.

4. **Content (list of topics to be developed):** Navigation equipment test complex and interface development approaches; Identification of necessary functionality for the user interface; Overview of test complex characteristics and testing process; Conceptual design of the user interface. Implementation using LabView software.

5. **List of required graphic material:** Images of software implementation of the user interface of the navigation equipment's test complex management system. Tables, figures.

6. Календарний план-графік

№ п/п	Завдання	Термін виконання	Відмітка про виконання
1	Отримання завдання	22.05.2023 – 23.05.2023	Виконано
2	Формулювання мети та основних завдань дослідження	23.05.2023 – 26.05.2023	Виконано
3	Аналіз існуючих методів	26.05.2023 – 31.05.2023	Виконано
4	Визначення параметрів випробувального комплексу та навігаційного обладнання	28.05.2023 – 01.06.2023	Виконано
5	Реалізація концептуального та програмного інтерфейсу користувача	30.05.2023 – 08.06.2023	Виконано
6	Оформлення пояснювальної записки	10.06.2023 – 14.06.2023	Виконано
7	Підготовка презентації та роздаткового матерілу	13.06.2023 – 14.06.2023	Виконано

7. Дата видачі завдання "22" травня 2023 р.

Керівник дипломної роботи: _____ Долгоруков С.О.

(підпис)

Завдання прийняв до виконання _____ Собко Д. Е.

(підпис)

6. Planned schedule:

№	Task	Execution period	Completion
1	Getting the task	22.05.2023 – 23.05.2023	Done
2	Formulation of the purpose and main objectives of the study	23.05.2023 – 26.05.2023	Done
3	Analysis of existing methods	26.05.2023 – 31.05.2023	Done
4	Determination of parameters of the test complex and navigation equipment	28.05.2023 – 01.06.2023	Done
5	Implementation of the conceptual and software user interface	30.05.2023 – 08.06.2023	Done
6	Preparation of an explanatory note	10.06.2023 – 14.06.2023	Done
7	Preparation of presentation and handouts	13.06.2023 – 14.06.2023	Done

7. Date of issue of the task "22" May 2023.

Qualification work supervisor: _____ S. O. Dolhorukov

(signature)

The task was accepted for work _____ D. E. Sobko

(signature)

РЕФЕРАТ

Пояснювальна записка кваліфікаційної роботи «Інтерфейс користувача системи управління випробувальним комплексом навігаційного обладнання».

40 с., 17 рис, 5 таб, 16 джерел.

Об'єкт дослідження: Контроль та моніторинг процесу тестування навігаційного обладнання випробувального комплексу оператором.

Предмет дослідження: Взаємодія оператора з інтерфейсом користувача системи випробувального комплексу навігаційного обладнання.

Мета: Розробити прототип дизайну інтерфейсу користувача системи випробувального комплексу навігаційного обладнання, що забезпечує управління та моніторинг роботи системи з боку оператора.

Метод дослідження: Огляд існуючих рішень щодо принципів, методів проектування інтерфейсу користувача та визначення вимог до інтерфейсу користувача шляхом дослідження процесу тестування та роботи тестового комплексу.

ABSTRACT

Explanatory note to the thesis "The user interface of the navigation equipment test complex management system".

40 pp., 17 figures, 5 tables, 16 references.

Object of study: The control and monitoring of the navigation equipment testing process of test complex by an operator.

Subject of study: User interface of the navigation equipment test complex system.

Purpose of the work: Develop a prototype design of user interface front-end of the navigation equipment test complex system that enables control and monitoring of the system by the operator.

Research methods: Overview of an existing solutions for user interface design principles, methods and identification of user interface requirements through research of testing process and test complex operation.

TABLE OF CONTENT

LIST OF SYMBOLS, ABBREVEATIONS, TERMS

TC	–	Test complex
NE	–	Navigation Equipment
TP	–	Testing Process
UI	–	User Interface
INS	–	Inertial Navigation Systems
IMU	–	Inertial Measurement Units
CAD	–	Computer Aided Design

INTRODUCTION

Relevance of the Topic. To ensure adequate reliability and conformity to established standards, navigation equipment must undergo a testing process as part of the manufacturing lifecycle. The usage of test complexes has become crucial in modern testing methodologies as they offer a controlled environment and capability for evaluating the parameters and operating modes of navigation equipment. As test complexes require high degree of precision and step-by-step procedures which are often accomplished through the automation of system, it leads to a need of designing the means by the operator can control and monitor the system.

Purpose and Objectives. The purpose of this work is to design user interface front-end of the navigation equipment test complex system that enables control and monitoring of the system by the operator.

The objectives are to define the principles of navigation equipment testing, what needs to be to be kept during the tests, the characteristics of the test complex system, its configuration, the role of an operator in the system and means of control to find the requirements for the user interface, basic interface elements, settings, controls and methods of its implementation.

Object and subject of the research. In this work object of research are means of control and monitoring of the navigation equipment testing process of test complex by an operator. The subject of this work is a user interface of the navigation equipment test complex system.

Methodology. The methodology of this work is to define the methods of testing navigation equipment and test complexes operation, make a literature reviews of current design principles for development of user interfaces, overview of current process control system examples and prototyping of the user interface.

Results of the work. The result of this work will be a prototype of the user interface that gives operator means by which to monitor the status of the test complex control the navigation equipment testing process, which can be used when designing a complete test complex system.

CHAPTER 1
NAVIGATION EQUIPMENT TEST COMPLEXES AND INTERFACE DEVELOPMENT APPROACHES

1.1. Testing of navigation equipment and types of test complexes

The testing process (TP) can be defined as a process of evaluating equipment's real performance in comparison to expected parameters [2] to conclude if the equipment is fit to be used in an intended manner. As equipment manufacturing involves strong adherence to the standards by which it must operate (often for the reason of its use in high-precision or dangerous systems, such as missile guidance), the act of testing consequently requires a high degree of accuracy when it comes to choosing methods that are going to be used in measuring equipment's performance.

In aviation navigation equipment (NE) are systems that are commonly used for measuring flight and navigation parameters that define the trajectory of an aircraft, without relying on external signals. [4] This category of systems encompasses various technologies, one example of which are inertial navigation systems (INS). Their primary application is to provide accurate and independent positioning and orientation information for the aircraft throughout its flight.

Before many of the components are installed in a more complex equipment (such as onboard autopilot), those components have already undergone individual testing, which makes it unnecessary to test them during assembly. When it comes to assembled equipment, it is often difficult (if not impossible) to conduct testing of such equipment for mechanical or electrical faults directly. As a consequence, the TP of assembled equipment is done by evaluating its operation performance, which can be done by the output data of the sensors installed in it.

To acquire both the position and angle of an aircraft combination of both accelerometers and gyroscopes are used, called inertial measurement units (IMU). As these systems consist of three accelerometers and three gyroscopes (and sometimes include magnetometers), the resulting complexity leads to some challenges when it comes to their testing. First, is that in assembled IMU each accelerometer and gyroscope is locked in one of three axis, which makes it a requirement to test each components performance with

consideration for its axis [2]. Second, each component has a specific method for evaluating its performance. This results in increase in number of testing and calibration procedures that need to be tracked, as well as increase in number of different parameters that need to be recorded and analyzed.
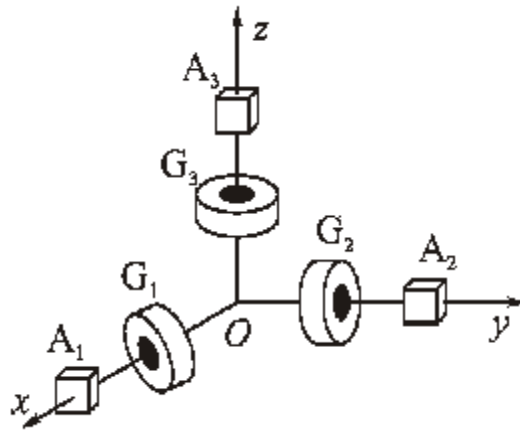

Fig. 1.1. Scheme of inertial measurement unit

The primary goal of a test complex (TC) is to confirm the tested object's reliability and compliance with the established standards, requirements, or performance criteria. TC provide systematic and repeatable testing techniques, which are necessary for the collection and analysis of accurate data. In order to assess an object's performance, identify any issues or defects, and confirm its capabilities, they provide a controlled environment for simulating real-world events.

The TC operate by making controlled changes in the position and angle of the equipment through directional or rotational motion, with makes it possible to evaluate and calibrate NE. These stands come in a variety of designs and exist in different degrees of freedom from one axis to six axes.

It is common practice to conduct tests and calibration of NE such as accelerometers, gyroscopes and INS using rate complexes (Fig. 1.1). Rate complexes operate by performing rotation of each axis at different specifiable rates. [1] These rate complexes come in three configurations such as one-axis, two-axis and three-axis rate complexes.

IMU are commonly tested and calibrated using three-axis rate complexes [2], as these motion platforms allow testing and calibration in all axis that typical IMU is expected to operate.

While use of test stand solves the question of how to test NE in different angle and position while maintaining accuracy, the TC increase the complexity of testing by adding new parameters that need to be tracked. If considering mentioned three-axis rate complexes, each of the gimbal can change its angle in 360 degrees at some angular velocity. It also must be considered that most rate complexes do not have exact same range of angles and angular velocities between all of three gimbals. This leads to increase in operational complexity, as two or more parameters must be monitored per each gimbal.
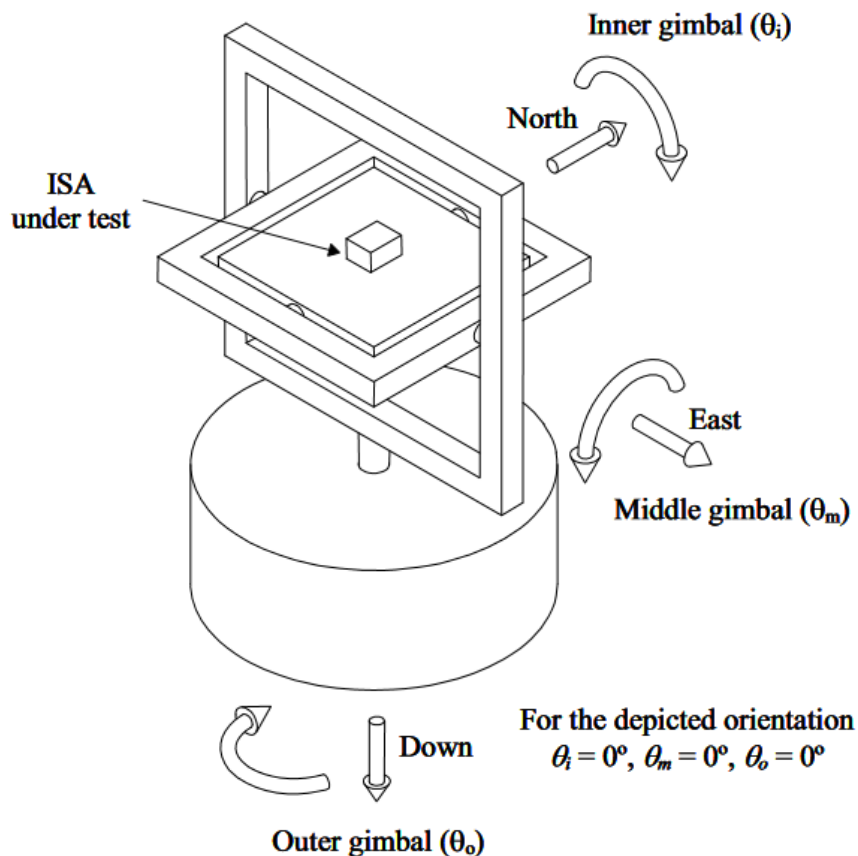

Fig. 1.2. Scheme of typical three-axis rate table

Nowadays most commercially available test complexes are supplied with electronic systems that allow direct control of its operations, though often the means of control and monitoring are rudimentary and do not allow to automate complex testing procedures. At

the same time these systems come with an option of connecting these test stand to a data acquisition system to control remotely [1]. This in turn allows to design a separate control system that allows more complex means of control that base TC aren't equipped to do.

1.2. The problem of monitoring, control and analysis of recorded data.

With the development of better methods for data acquisition it became much easier to track changes in the system in real time

By displaying the data in a real-time the performance of a testing procedure can be evaluated on sight, which the operator can use to conclude if the test proceeds as expected or if it is required to stop the procedure and make changes before repeating the test. [1] The TC can also benefit from real-time monitoring system by making sure that the test stand operates correctly right before any NE testing is started. This allows to evaluate the state of a TC much more frequently, shortening the time between each test. In the systems that allow automation of TP it is necessary to provide an option to upload the instruction to the control system.

It is common to analyze acquired data using various methods such as plotting versus time or data filtering such as identifying equipment's self-noise noise. [1] The results of those calculations can assist in identifying data trends, patterns, and deviations from expected values, allowing the operator to evaluate the equipment's accuracy, stability, and responsiveness.

Monitoring entails a significant amount of data output obtained during NE testing. During the use of navigational equipment, an array of data is produced that records various parameters such as position, direction, velocity, and acceleration. This dynamic data provides real-time information about the equipment's operation and performance. This creates a problem in which the amount of data is too large to manually store or analyze.

1.3. User interface design approaches, software, comparison of existing interface implementations for test complexes

Currently majority of commercially available test monitoring systems [5,6] take approach of merging the task of monitoring and controlling the testing procedures into a

single interface display. These interfaces allow monitoring and control of position, velocity and acceleration, as well as display those settings in real-time. These systems provide their own control systems and means of interfacing with test stand hardware, but depending on the test requirements and existing hardware architecture this does mean that those monitoring systems might not be appropriate for all test complexes.

An example of such system can be ACUTROL 3000e Controller (Fig 1.3.), that provides functions like real-time parameter observation and real-time graph display of a test complex operation. [5]
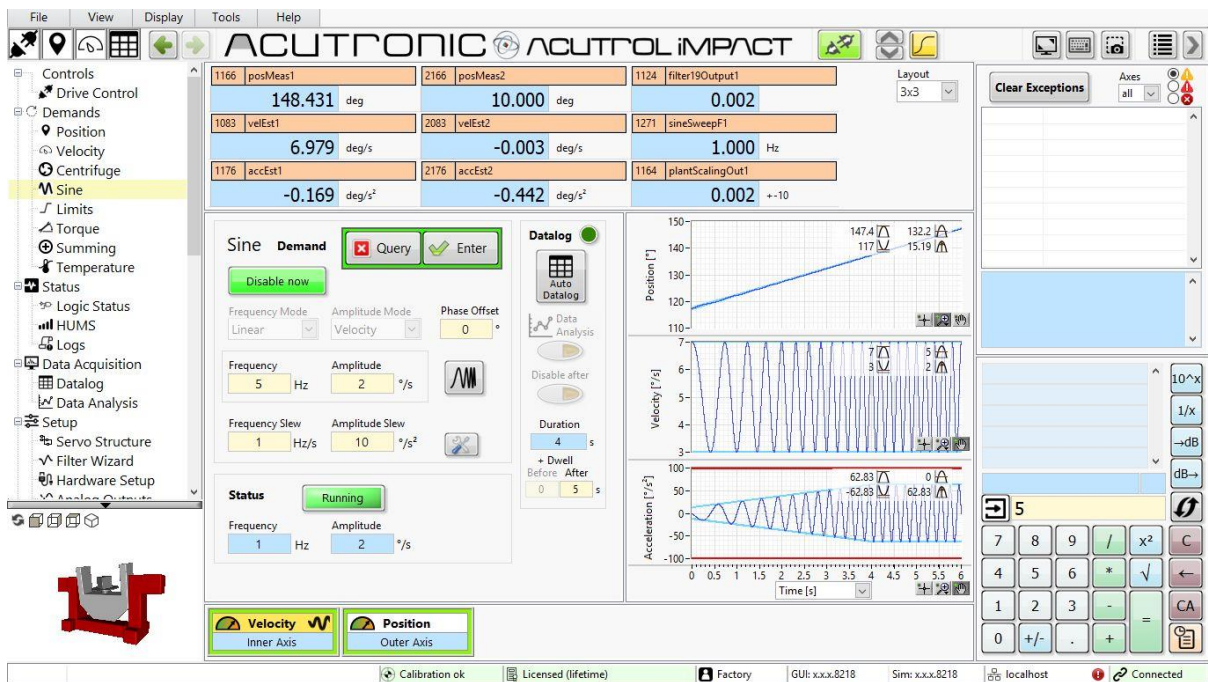
Fig. 1.3. ACUTROL 3000e Controller user interface

While manufacturing facilities can benefit from installation of such system, in education and research, or for custom testing processes those solutions are costly, have unnecessary functionality and often incompatible. Education institutions largely use portable software that can be installed to personal computers, and in industrial applications the company might prefer to install interface on existing hardware.

It's becomes much more common to use Computer-Aided-Design software to simplify the development of various aspects of equipment manufacture. In the context of

interface design, it can be used to display parameters and control functionality using preexisting interface development software and modules.

In many works involving creating of TC, parameters monitoring and control implementation [7, 8, 9] one of the CAD software commonly proposed is LabView. LabView (Laboratory Virtual Instrumentation Engineering Workbench) [10] is a CAD software by National instruments that is used for a purpose of graphical UI design, hardware interfacing and simulation testing.

The ability to communicate with hardware components and common communication protocols in TC is provided by LabView. It can both support various data collection devices, control systems, and communication interfaces. It was shown to aid in the creation of display panels, as LabView offers charts, graphs, meters, and indicators, which are capable of displaying data acquired from the TC in real time. These visual representations enable operators to intuitively assess test results and keep an eye on key factors, increasing the overall effectiveness of the TP.

Despite that other software such as MATLAB [11] was shown to be better for the analysis and filtering of acquired data, but it does not have built in capabilities for designing more manageable UIs.

With regard to TC, it can be said that LabView's capabilities are considerably more suited to monitoring and control of TP, as well as managing data acquisition from the TC hardware, but depending on the requirement other software can be connected to offload tasks of analysis and filtering.

1.4. Task statement for interface development

The task of developing UI is to implement an interactable front-end interface for the purpose of displaying, controlling and configuring the operation of TC and NE within the required operating parameters on the stage of equipment exploitation.

The primary goals of interface can categorized into three groups (Fig. 1.4):

1. Monitoring of test stand operation in real-time.

A critical component of the whole TP is the real-time monitoring of test stand operation. It involves continuously monitoring and keeping an eye on the test stand's

performance and behavior throughout various test procedures. The UI must have the required capabilities to display and track important test stand operation metrics in order to perform successful monitoring. Real-time monitoring of the test stand's position (yaw, pitch, and roll), speed, and acceleration is part of this.

Additionally, the UI must keep track of any potential errors or deviations from the specified criteria. Users can be informed in real-time if any unusual behavior or parameter thresholds have been surpassed by implementing alerts and notifications. This will lead to overall safety and effectiveness of the TP being improved since operators are able to take immediate corrective steps when necessary.

1. Gathering and analysis of test data from tested equipment.

The functionality to save and evaluate test data from the equipment being tested is required of the UI. In order to do this, interface has to give options for the recording and storage of relevant data gathered during the TP for later analysis and evaluation. The UI needs to have panels specifically for recording data that let users choose particular channels and data acquisition parameters.

The UI should show real-time graphs and charts of the acquired data as soon as the data acquisition process is started. The UI for navigational devices like accelerometers should display graphs that show the data that was recorded for each selected axis (X, Y, and Z). This makes it possible for users to checks on the behavior and functionality of the tested equipment as it is being used.

2. Control of the TC.

Additionally, the UI needs to offer complete TC control capabilities. In order to ensure precise and controlled motions of the moving parts in line with the testing protocols. The UI should provide simple inputs and controls that let users enter the desired motion control parameters. For each moving axis, this involves picking the starting positions (for example zero degrees for yaw, pitch, and roll), target velocities, and target accelerations. In order to ensure simplicity of use and effective control, the UI should offer obvious options for entering these parameters.
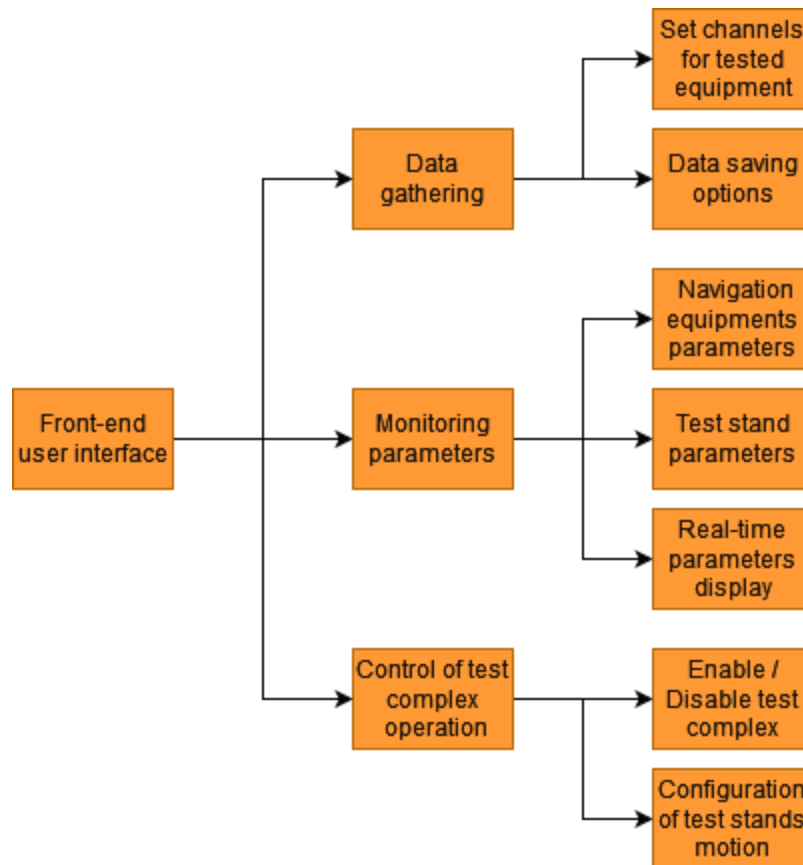
Fig. 1.4. Task of interface development.

To ensure that the design process of UI is carried out effectively and considers every aspect of test complex and role of an operator, the principles outline in ДСТУ ISO 11064-1:2009 [15] (Fig.1.5):

- Clarification of the project's aim, substance, resources, and limits is done at the onset while taking into account current circumstances that might serve as a baseline for comparison.

- Analysis and definition of the basic tasks and functions of TC, functional and operational requirements.

- Create the initial design concept, which includes layout of the interface, including the controls, and monitoring panels.

- Create detailed design concept by establish technical specifications for the tasks associated with designing the UI, including the information it will contain, the operational interfaces it will use, and the workspace technology.

- Evaluate the results after its completion to see if it is necessary to make any changes and go back to previous stages of design.
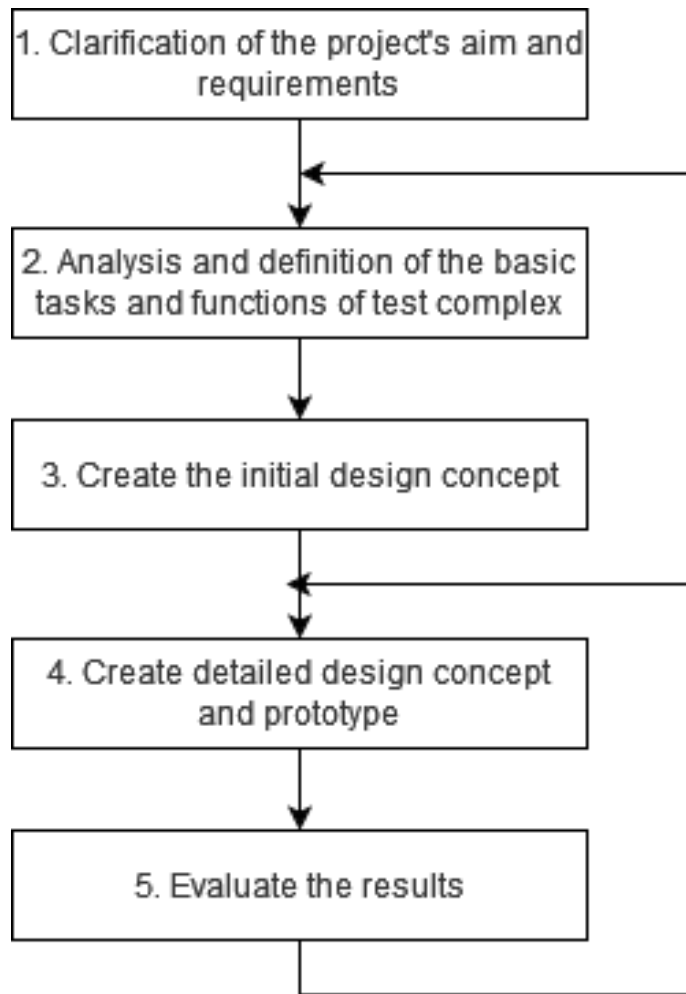
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Fig. 1.5. Principles of interface development.

CONCLUSIONS

When assessing an item's performance and establishing if it is suitable for usage, testing is required step. It is well established that precise testing procedures are required guaranteeing adherence to operational standards, particularly in highly precise and crucial systems like NE. To verify the parameters of the tested object with established standards, TC are used. They offer systematic and consistent testing methods as well as controlled environments for mimicking real-world occurrences. NE is frequently tested and calibrated using rate complexes, which rotate each axis at several specified rates.

The large amount of data generated during NE testing is a challenge for monitoring, managing, and evaluating recorded data. Operators can assess the effectiveness of testing methods and guarantee that test stands are operating correctly thanks to real-time monitoring systems. Plotting data against time and data filtering are two examples of data analysis techniques that can be integrated into testing process using UI to identify trends, patterns, and departures from expected values during testing process. This allows for a precise assessment of the accuracy, stability, and responsiveness of the equipment.

The goal of creating an UI is closely linked to the control and monitoring of the test complex operation, the collection and analysis of test data. As such it is necessary to clearly define the characteristics of the system before any consideration for the UI design and functionality can be made.

CHAPTER 2

INDENTIFICATION OF NECESSARY FUNCTIONALITY FOR THE USER INTERFACE. OVERVIEW OF TEST COMPLEX CHARACTERISTICS AND TESTING PROCESS

2.1. Stages of identifying requirements for the user interface

The necessary parameters and functionality for UI must be identified before work on its implementation can be started

Before any testing procedure may be started it is required to first outline the equipment and testing procedures [1]. By specifying this, it can be possible to identify what parameters is necessary to display and what controls are required from the interface. The steps to accomplish this are similar to the steps required outline the structure of the TC (Fig. 2.1)
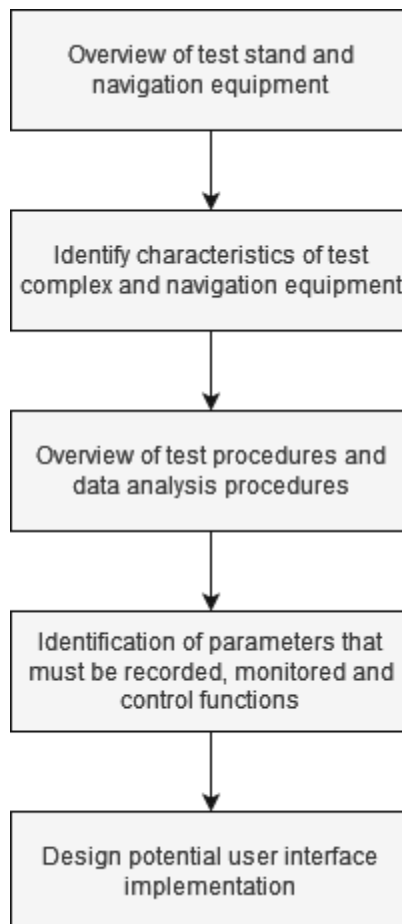

Fig. 2.1. Stages to identify test complex parameters required to implement user interface

The design and development of a UI can be done during the planning phase of a TC design. To demonstrate this, examples of parameters based on existing NE and TC will be used to develop UI, and procedures for TC operation will be chosen depending on the TC parameters.

To simplify the process of evaluating UIs, the tasks of monitoring and controlling the test stand and measuring and analyzing the performance of NE will be considered independently. Furthermore, the methods by which the hardware and software are linked are not explored.

2.2. Test complex and navigation equipment's characteristics overview

The LIS3LV02DL [12] is a MEMS digital output linear accelerometer manufactured by STMicroelectronics that is designed with three axes of measurement (Fig. 2.2). It is made up of a sensor component and an IC interface for processing data from the sensing component. The accelerometer has an I2C/SPI serial interface that enables communication with external devices of the measured acceleration signals.

The LIS3LV02DL's sensing component can be used for precise acceleration measurement. The range of acceleration can be selected between either 2 or 6 g. Additionally, the accelerometer offers a bandwidth of 640 Hz for all axes.

Table. 2.1

Specification of LIS3LV02DL MEMS accelerometer

Technical characteristics	Value
Number of axes	3-axis
Acceleration (g)	±2 or ±6
Resolution (bit)	12 bit, 16 bit.
Frequency (Hz)	640

The Three-Axis AC33V-T450 Series Inertial Guidance Test and Calibration System [14] was chosen since it can be utilized for rigorous testing and calibration of IMUs as well as MEMS testing. Its capabilities include precise simulation of a equipment's roll, piTCh, and yaw motion in a three axis, with no rotational restriction, allowing full continuous

motion. It simplifies the process of designing monitoring systems because it lacks drift and has high velocity stability.
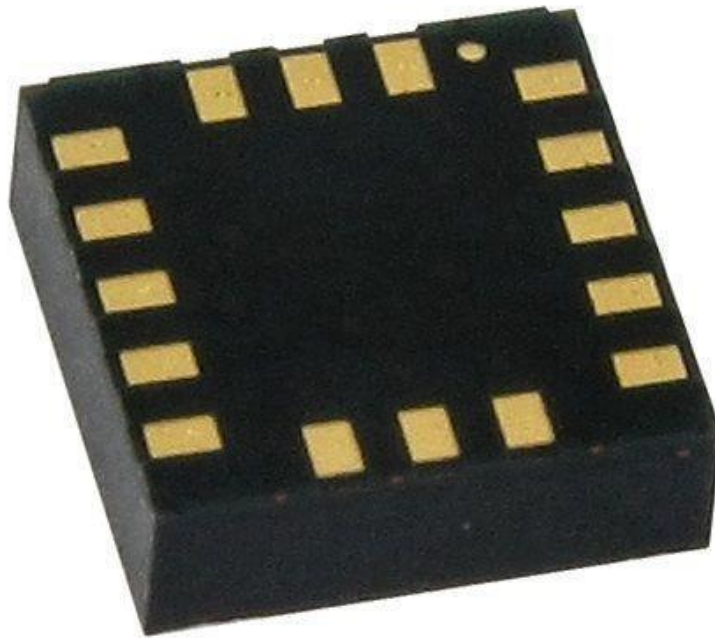

Fig. 2.2. LIS3LV02DL MEMS accelerometer

Table. 2.2.

Specification of three-axis AC33V-T450 rate table

Technical characteristics	Axis	Value
Number of axis		3 axis
Position range, deg	Yaw (Inner Axis)	±380 deg
	Pitch (Middle Axis)	±380 deg
	Roll (Outer Axis)	±380 deg
Maximum velocity, deg/s	Yaw (Inner Axis)	1500 deg/sec
	Pitch (Middle Axis)	400 deg/sec
	Roll (Outer Axis)	400 deg/sec
Maximum acceleration, deg/s^2	Yaw (Inner Axis)	3000 deg/sec^2
	Pitch (Middle Axis)	400 deg/sec^2
	Roll (Outer Axis)	400 deg/sec^2

In addition to NE the system must be connected by the hardware that is capable of data acquisition and control. The structure of complete TC installation can be seen on the Fig. 2.4.

Fig. 2.3. Three-Axis AC33V-T450 rate table

2.3. The tasks of the testing process and procedure

As previously stated (see Fig.1.4), the purposes of creating UIs are classified into three groups. To achieve these objectives, two procedures will be considered, which will serve as the foundation for the interface's implementation.

For the task of motion control and monitoring of parameters in real time, the procedure should involve motion of each gimbal individually, motion of all gimbals simultaneously. All the recorded data must be displayed and saved:
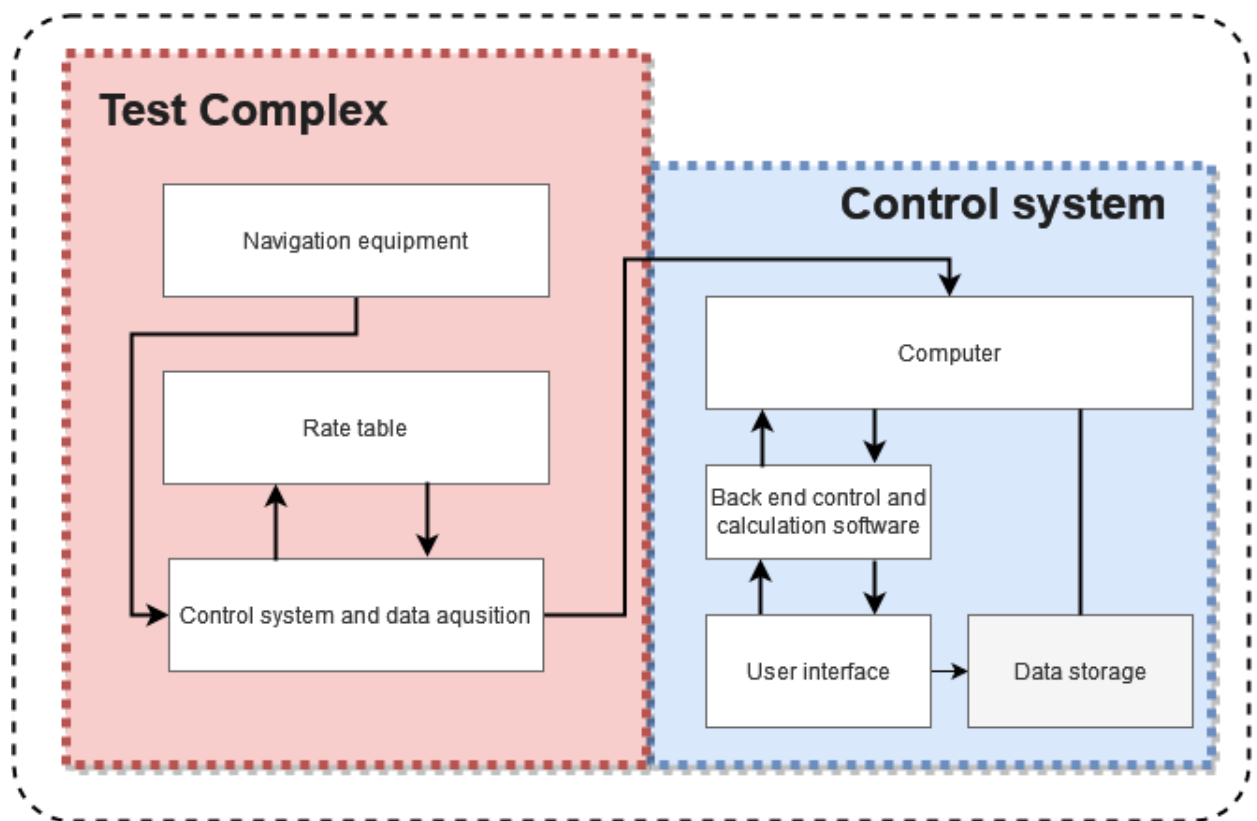
Fig. 2.4. The structure of test complex

1.   Check that the 3-axis rate table is turned on and that all safety precautions have been performed.

2.   Align each gimbal with its corresponding home position to set the starting position to 0 degrees.

3.   Choose target velocity of 36 deg/sec, target acceleration to 13 deg/sec^2.

4.   Test movement of individual gimbals:

a. Inner Gimbal (Yaw): Begin 360-degree controlled rotation in the yaw axis.

b. Middle Gimbal (Pitch): Begin a controlled 360-degree rotation in the pitch axis.

   c. Outer Gimbal (Roll): Begin a controlled 360-degree revolution in the roll axis.

5. After completing the individual movements, proceed to the simultaneous rotation of all axes. Select a last position at positive 180 degrees. Begin a controlled 180 degree rotation in all axes (yaw, pitch, and roll) at the same time.

6. All gimbals should be aligned with their respective home position after finishing the necessary motion in order to return them to their initial position of 0 degrees.

7. After the procedure is over, power off the rate table.

For the task of monitoring, recording and analysis of NE the procedure can involve analysis of accelerometers characteristic.

As LIS3LV02DL is a MEMS accelerometers sensor, it shares a characteristic self-noise that all of the MEMS accelerometers are prone to impact. [2, 13]. For this reason, it can be beneficial to fully describe the self-noise of these sensors, as this characteristic can impact any INS or IMU systems they may be installed on.

The effect of self-noise on MEMS sensors can be analyzed using Allan's variance method [2, 12], which can be applied to the LIS3LV02DL sensor.

The coefficients R, K, B, N, and Q, which represent random acceleration:

$$\sigma_A^2(\tau) = R^2 \frac{\tau^2}{2} + K^2 \frac{\tau}{3} + B^2 \frac{2}{\pi} ln2 + N^2 \frac{1}{\tau} + Q^3 \frac{3}{\tau^2},$$

where R represents a quasi-deterministic fluctuation in the input acceleration; K corresponds to the random walk of the acceleration.; B indicates the instability of the zero offset; N refers to the random velocity wander, which is often characterized as white noise; Q represents the quantization effect on the output signal.
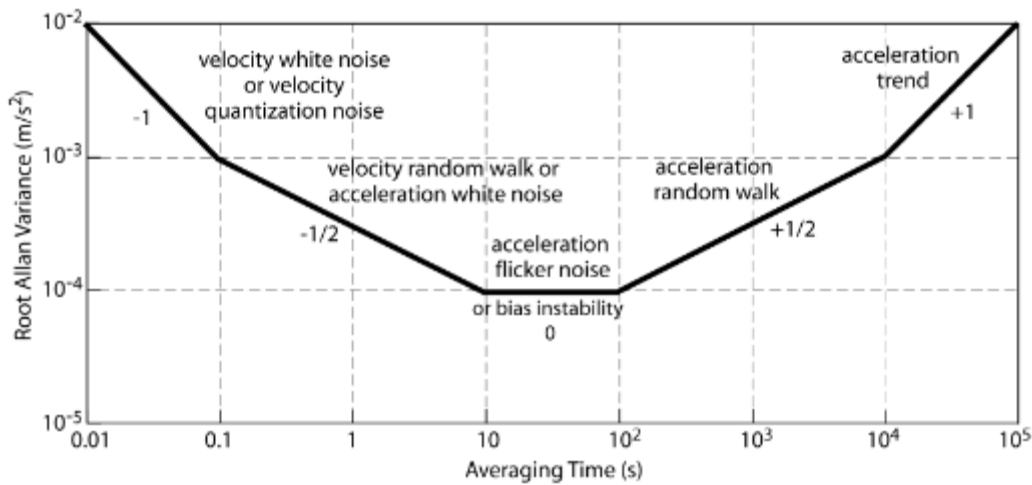

Fig. 2.5. Example of graph of square root change σ_A^2 depending on the correlation interval τ for the output signal accelerometer.

The procedure will recording of accelerometers Ox axis, which will be analyzed by Allan variance module.

1.   Place the NE in a static position with Ox axis pointing to the north.

2.   Select NE recording panel.

3. Select the folder location data must be saved to.

4. Select accelerometer channels that must be recorded.

5. Begin the data recording procedure. The procedure should be performed for one hour to collect a considerable volume of data while the NE remains stationary. Monitor the graph of acceleration channels.

6. Stop the data acquisition procedure once the acceleration data has been recorded.

7. Check if the acquired data is saved correctly.

8. In the analysis interface, select the Allan variance analysis option.

9. Once the software generated the necessary statistical parameters, examine the Allan variance plot and statistical findings to assess the noise characteristics of the NE's acceleration.

10. Document and analyze the results.

11. Save the acquired graph for future use.

12. Close the analysis interface and power off the TC.

2.4. The requirement for user interface Parameters that need to be recorded

With knowledge of testing procedures and parameters that must be monitored it can be possible to derive the criteria for functionality of UI.

Table. 2.3

Criteria for user interface implementation

Functionality criteria	Parameters that must be recorded
Monitoring of rate table operation	Position (yaw, pitch, roll) Velocity Acceleration Graph of position (yaw, pitch, roll)
Motion control of rate table	Starting position (yaw, pitch, roll) Final position (yaw, pitch, roll) Target Velocity Target Acceleration
Monitoring of NE	Acceleration Graph of acceleration
Data analysis	Accelerometers acceleration

Range of parameters that must be displayed

Parameters	Axis	Range of values
Position range, deg	Yaw, Pitch and Roll	From -180 to 180
Maximum velocity, deg/s	Yaw (Inner Axis) Pitch (Middle Axis) Roll (Outer Axis)	From – 1500 to 1500 From -400 to 400 From -400 to 400
Maximum acceleration, deg/s^2	Yaw (Inner Axis) Pitch (Middle Axis) Roll (Outer Axis)	From –3000 to 3000 From -400 to 400 From -400 to 400
Accelerometer acceleration	X axis, Y axis and Z axis	From - 2 to 2

As all of the three gimbals of rate table can rotate in both direction and accelerometer can record acceleration in both direction of each axis, it can be concluded that the UI should display both negative and positive range of values.

CONCLUSIONS

It was examined that the definition of main characteristics for the navigation equipment test complex management system are necessary to define the functionality of the user interface. First the stages of defining the characteristics of the system were set. Then the parameters that needed to be displayed were determined and the controls that were crucial for the interface by specifying the hardware and testing methodologies.

A general overview of the test complex's features and navigational equipment testing was made. In particular, the MEMS accelerometer and Three-Axis Rate Table were chosen.

The requirements for the user interface's functionality based on the testing procedure and parameters were defined. These requirements included performing data analysis as well as monitoring rate table operation and motion control, as well as recording of the navigational equipment. The limiting range of the parameters was also set based on the characteristics of the equipment.

CHAPTER 3

CONCEPTUAL DESIGN OF THE USER INTERFACE. USER INTERFACE. IMPLEMENTATION USING LABVIEW SOFTWARE

3.1. Stages of user interface design

The development of a general design concept and its implementation using software is the main goal of this chapter.

Before implementing UI it can be beneficial to consider what end result is required first through conceptual planning. During the conceptual design stage [15] it is required to define functional objectives based on the established characteristics of the system. The role and interaction of an operator with the UI must also be considered, as an operator is key part of the system

3.2. Role of operator in the design of user interface

The operator must be factored in when considering the functions of UI. As operator is also a part of testing operation, its role in the TC must also be considered when designing the UI.

The duties of operator include:

- Control the test procedure.
- Monitor the correct operation of TC.
- Monitoring of the parameters of NE.

Operator are necessary for the safe and effective operation of test complex. They are depended on visual control and monitoring displays to acquire critical information and conduct actions that assure the operation of TC is correct.

The test complex and operator are closely tied and effectiveness of one is depended on the other. The operators role is to define the way the automated system should perform, and as such the operator needs the way to input commands to the TC.

User interface should provide features that allow operator to know and control every state of the TC during its operation. The UI should provide features such as operation initiation and termination, which can occur in a variety of modes to fulfill specific

requirements. Furthermore, operators should be given ways to dealing with unforeseen events, such as discovering fault and making corrective steps as soon as possible.

When testing the NE, the operator must have necessary knowledge to make educated guess on the status of the testing process. If the operator is given the data on the test stand position and navigation equipment's parameters in real time, they can make a decision on the result of the testing on spot.

3.3. User interface layout, panels, elements, controls and settings

The performance quality of a user interface is an important aspect in determining its usability. It is determined by the operator's ability to quickly notice and interpret situations, as well as their ability to respond properly. Several critical factors contribute to high-quality performance in a user interface. One critical part is readability, which means how quickly operator can recognize any changes in the test complexes working conditions.

Understanding the information displayed on the interface is another key factor. Clarity and precision are critical for avoiding any decisions that can negatively affect the operation of the test complex. The displayed information should be clear and understandable, allowing the operator see it quickly. The information presented on the screen or display unit should be easily visible and not cluttered. Additional colored indicator should be considered that can grab operators attention to the specific information, like fault or if test complex is operational.

Judging from this, the interface functionality can be divided by its operating modes:
- Control of TC operation;
- Input of required operation modes and motion parameters by the operator;
- Display of real-time parameters to oversee the operation status of the TC;
- Display of the test results for operators evaluation and further analysis.

The interface sections can be divided accordingly into different panels (Table 3.1) that are intended to perform a set task. This will help the operator clearly see for what task each of the panel is supposed to be used. [15]

Functional blocks of the user interface

Panels	Parameters and functions
Operation control panel	Operation and motion control
	Emergency Stop
	Per axis control
Motion parameters	Select operation modes
	Control of rate table positioning
	Control of rate table acceleration
	Control of rate table positioning
Display of parameters	Rate table position
	Rate table velocity
	Rate table acceleration
	Current position graph
	Acceleration graph
	Indicators
Analysis of results	Data recording and saving
	Position graph
	Acceleration graph

When considering the layout of the interface, it is necessary to consider the performance of operator when using the UI, which is largely based on operator's ability to quickly notice and interpret situations, as well as their ability to respond properly. One critical part is detection, which means how quickly operator can recognize any changes in the test complexes operation. The information presented on the screen or display unit should be easily visible and accessible. Dividing panels based on their purpose, as well as adding elements like flashing indicators and diagrams can be beneficial in guiding the operators attention to the necessary information about the state of test complex operation.

On these principles the layout of the interface can be made (Fig 3.1).

3.4. Software implementation

Each of the functional element of the UI requires to be implemented separately, but this leads to lengthening of time for the development of a final UI design. This necessitates a quicker CAD alternative which provides preexisting configurable elements that fill all of the requirements.
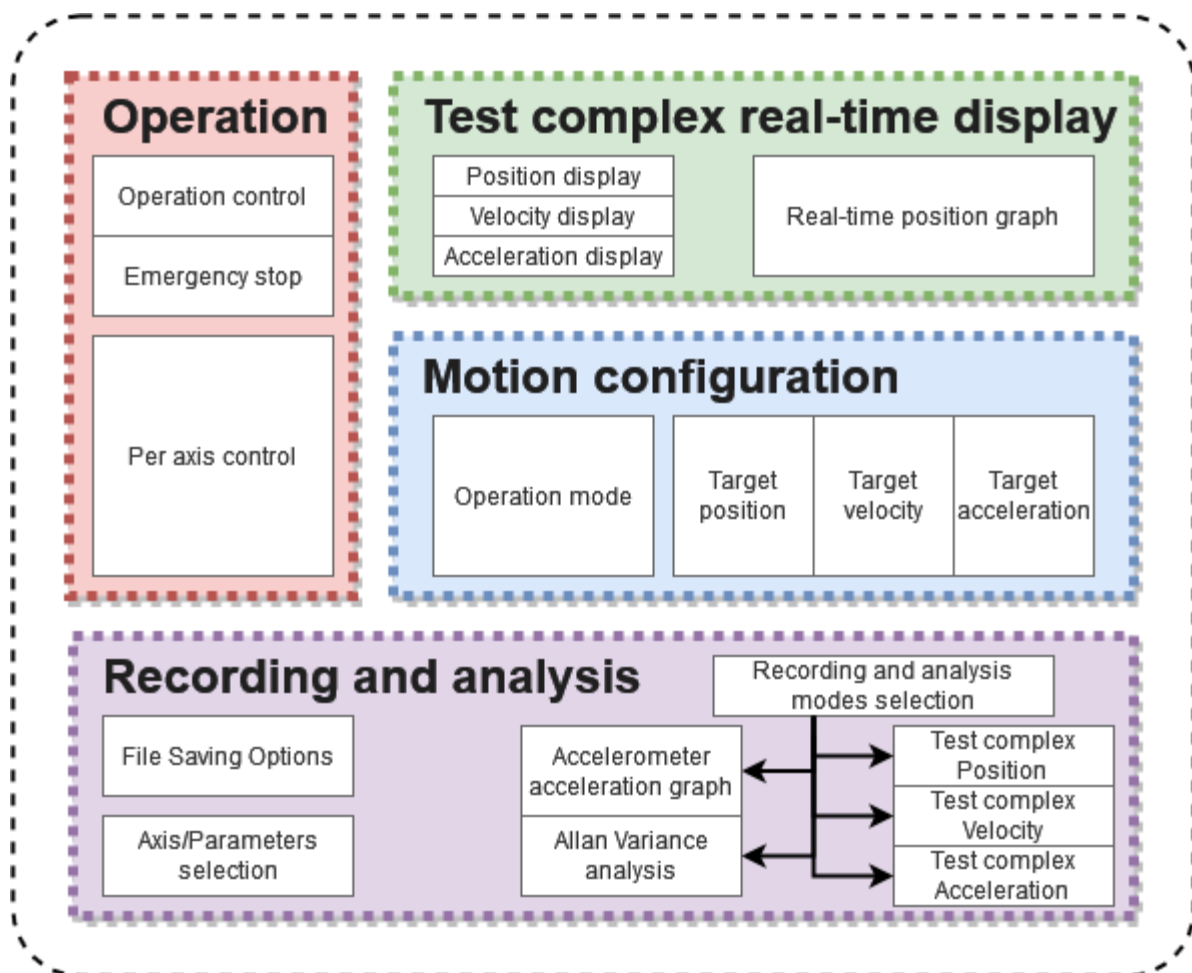
Fig. 3.1 The layout of UI

For correctly implementing the above requirements for testing complex procedures, LabVIEW can be proposed. LabVIEW is designed specifically for the task of implementing UI for the industrial control and monitoring with build in display elements. The software's graphical programming interface can also help to place interface elements in necessary layout with drag-and-drop functionality.

As the LabVIEW provides data acquisition and signal processing functionality, it can be used for further implementation of in-depth data analysis of recorded data, with display of it using functions like graphs.

During TC development one of the goals is to implement hardware integration between the TC and UI. As LabView provides functionality to interface with the hardware and data acquisition, the GUI made using it can be further extended at any stage of the development.

The instrumentation within LabView that can fulfil the requirements for a TC functions are outlined in table 3.2.

Table. 3.2

Functionality of TC with use of LabView instrumentation

Parameters and function	Task	LabView instrumentation
Rate table position	Display 360 degrees position of each gimbal axis	Numeric Indicators
Rate table velocity	Display current velocity of each gimbal axis	
Rate table acceleration	Display current velocity of each gimbal axis	
Current position graph	Display current position as a graph	Waveform Chart
Acceleration graph	Display entire acceleration data of selected axis from the start of the TP to the end	Waveform Graph
Operation and motion control	Enable or disable the motion of all or selected axis	Boolean switches or buttons
Emergency Stop	Completely stop the operation of TC	
Select operation modes	Selection between position and velocity mode	
Control of rate table positioning	Set target 360 degrees position of each gimbal axis	Numeric Control
Control of rate table acceleration	Set target acceleration of each gimbal axis	
Control of rate table positioning	Set target position of each gimbal axis	
Data recording and saving	Select the file name and file path where recorded data will be saved	File Path Control
Indicators	Indicate or warm of the current status of the TC	Boolean LED

3.5.   Final user interface design

The implementation of individual panels can be seen from Figure 3.2 to Figure 3.5.

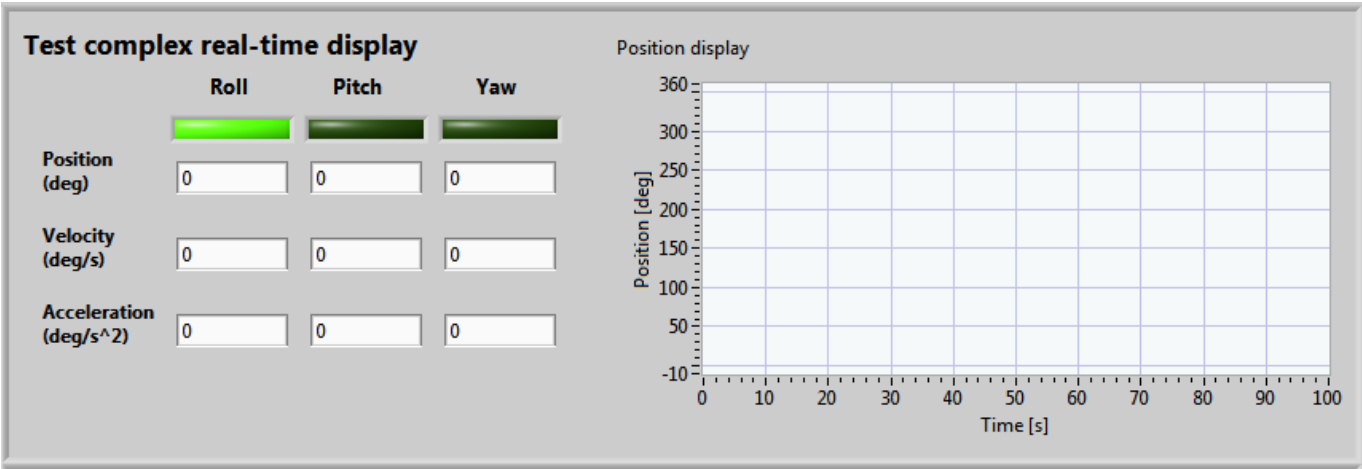Fig. 3.2 LabView implementation of operation panel

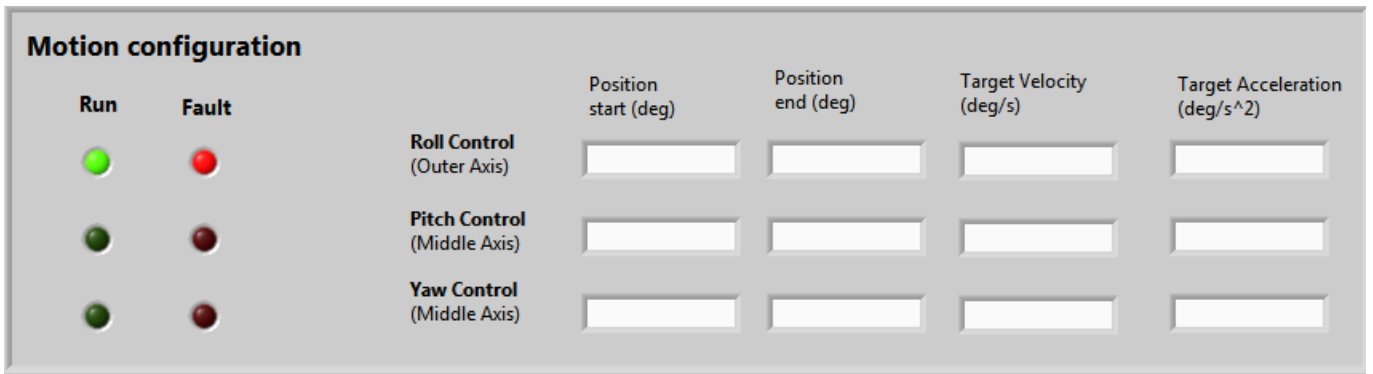Fig. 3.3 LabView implementation of real-time display

Fig. 3.4 LabView implementation of motion configuration
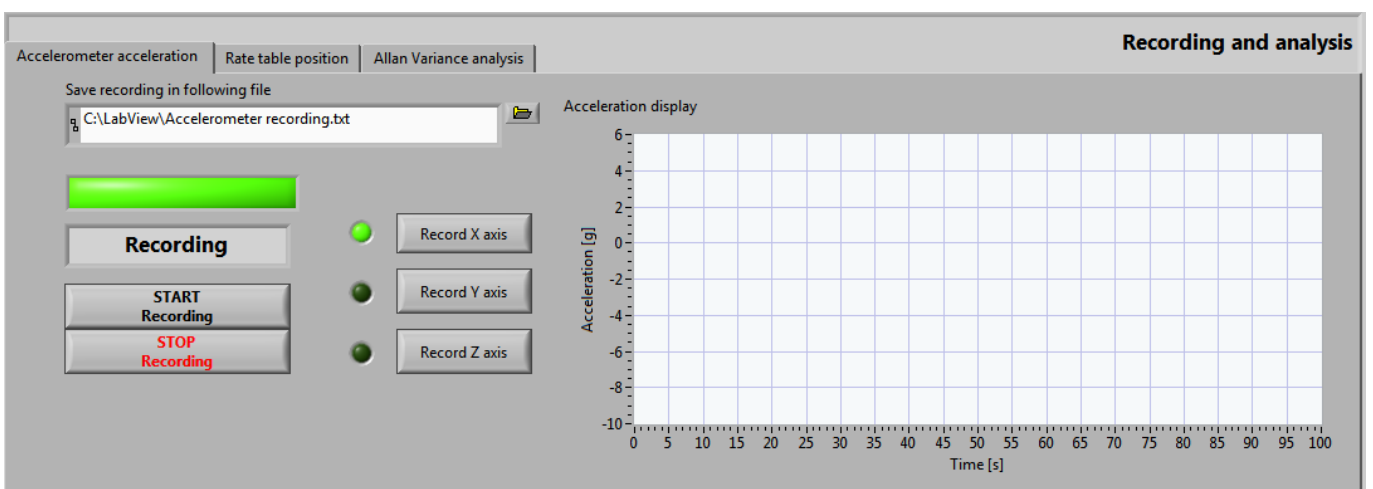

Fig. 3.5 LabView implementation of recording and analysis display

The complete user interface design can be seen on Figure 3.6.

The stages of use of the user interface (Fig. 3.7) are aligned with the testing process. This help in keeping operators attention to the specific panel, where operator can monitor one panels at a time.

The control for test complex operation, such as movement of each gimbal and emergency stop are located on one panel, so in case of any fault operator can quickly find where to stop the testing process if necessary.
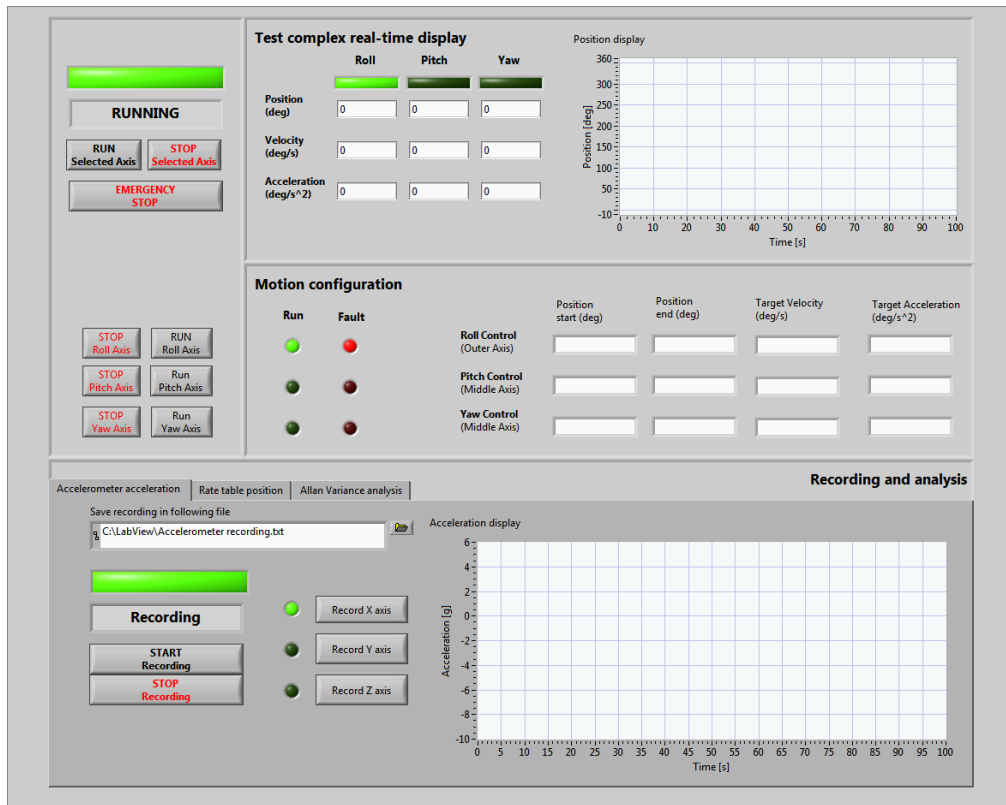
Fig. 3.6 Final user interface design

The operator is required to use user interface in steps, each of which are tied to a specific panel described before.
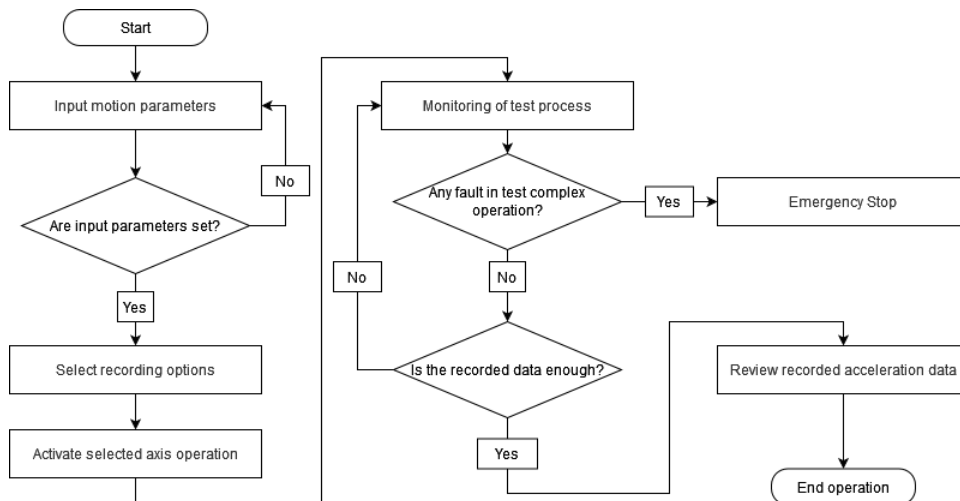

Fig. 3.7 The process of user interface operation.

On the chart above one can see algorithm of user interface operator actions in the process of UI testing.

CONCLUSIONS

In order to improve the effectiveness of test complex operation, the user interface of the navigation equipment test complex management system was designed. It was concluded that the iterative design that takes into consideration the characteristics of the test complex and its operation is necessary to ensure the user interface functions align with the goals set by the testing procedures.

The test complex operation monitoring and control is overall improved by the designed user interface, with visual feedback from the system providing improved visual feedback to the operator on the status of the test complex and testing. The control of the test complex is made easier by giving simple control inputs that help with making time efficient changes to the motion and operation of the complex. The methods for recording data also simplify further analysis of the acquired data while allowing further expansion with methods that allow the analysis of navigation equipment's characteristic on site.

There are still some areas that need additional focus and refinement, which makes it necessary to return to previous stages of test complex planning with considerations made with current user interface. A clearer definition of the testing process is required to further implement and if necessary, change the functionality of the user interface.

Furthermore, in this work only the user interface and the means by which it is operated were considered. To implement the software that can display the gathered data and connect with the test complex to control the system of the test complex it is necessary to define the data acquisition methods, but the software can be easily expanded within LabView.

A feedback from the operator of the potential navigation equipment test complex is to be gathered in details to make any necessary changes during implementation phase of the test complex.

References

1. IEEE Std 1554 ™ -2005 IEEE Recommended Practice for Inertial Sensor Test Equipment, Instrumentation, Data Acquisition, and Analysis

2. Аврутов, Вадим Вікторович, ВИПРОБУВАННЯ І КОНТРОЛЬ ПРИЛАДІВ І СИСТЕМ, 2022.

3. Gregory K. McMillan., Process/industrial instruments and controls handbook, McGRAW-HILL, 1999, 1331p.

4. Автономні системи навігації конкретного типу повітряного судна та їх технічне обслуговування: навч. посібник / В.О. Рогожин, А.В. Скрипець, М.К. Філяшкін, М.П. Мухіна – К.: НАУ, 2015. – 308 с.

5. Multi Axis Digital Motion Control System ACUTROL®3000e Controller Datasheet.

6. AERO 4000 Precision Motion Controller Datasheet

7. Tasner T, Lovrec D. Flexible TC based on LabVIEW. Annals of the Faculty of Engineering Hunedoara. 2012;10(1):119.

8. K. R. Aaron, N. L. Foster, D. P. Hazel and A. M. Hasanul Basher, "Closed-loop position control system using LabVIEW," Proceedings IEEE SoutheasTCon 2002 (Cat. No.02CH37283), Columbia, SC, USA, 2002, pp. 283-286.

9. Asvahem T, Claudio C, Shetty D. Graphical UI Product Simulation For Motion Control Of Mechine Path. In2004 Annual Conference 2004 Jun 20 (pp. 9-647).

10. National Instruments: NI LabVIEW, https://www.ni.com/docs/en-US/bundle/labview/page/lvhelp/labview_help.html.

11. Tašner T, Lovrec D, Tašner F, Edler J. Comparison of LabVIEW and MATLAB for scientific research. Annals of the Faculty of Engineering Hunedoara-International Journal of Engineering. 2012.

12. MEMS inertial sensor 3-axis 2g/6g digital output low voltage linear accelerometer, LIS3LV02DL Datasheet. STMicroelectronics, 2008.

13. D'Alessandro A, Vitale G, Scudero S, D'Anna R, Costanza A, Fagiolini A, Greco L. Characterization of MEMS accelerometer self-noise by means of PSD and Allan

Variance analysis. In 2017 7th IEEE International workshop on advances in sensors and interfaces (IWASI) 2017 Jun 15 (pp. 159-164). IEEE.

14. Three-Axis AC33V-T450 Series Inertial Guidance Test and Calibration System Data Sheet. ACUTRONIC, 2020.

15. ДСТУ ISO 11064-1:2009 Проектування центрів керування ергономічне. Частина 1. Принципи проектування (ISO 11064-1:2000, IDT).

16. Fink R, Hill D, O'Hara J. Human Factors Guidance for Control Room and Digital Human-System Interface Design and Modification. Guidelines for Planning, Specification, Design, Licensing, Implementation, Training, Operation and Maintenance. EPRI (US). 2004.