Military Technical College
Kobry Elkobbah
CAIRO - EGYPT

8th INTERNATIONAL CONFERENCE
ON AEROSPACE SCIENCES &
AVIATION TECHNOLOGY

Integrated Educational Guidance, Navigation, Control and Signal Processing Laboratory

*Gamal A. El-Sheikh**

Abstract:

The growth and added importance for the field of navigation, guidance and control, from day to day since the second world war in the forties, necessitates a jump in the educational facilities concerning this field. In addition, there are many challenges facing the guidance engineer such as information availability, system design complexity, the ever-increasing requirements with the possibility of unstable or tolerable environments and the limited or restricted literature. These limitations did not allow the guidance engineer to grasp a sound understanding and knowledge of the fundamental principles involved in missile test, design and evaluation which known as the know-how of missile design. The guidance engineer should have a broader view and hence a better appreciation of the various design aspects in order to achieve a more efficient design. That is; the today's guidance engineer needs to understand the details of guidance as well as the details of interfacing with different disciplines in an automated environment. To address these needs, a guidance, navigation, control and signal processing laboratory has to be implemented.

Therefore, this paper is devoted to give a systematic and concise explanation on this type of laboratories. It could be appropriate for undergraduate and graduate students as well as those practicing and searching and/or manufacturing in the field. Due to the nature of the guidance and control, a highly mathematical background is needed for their synthesis and analysis. The paper offers a structure for the laboratory including different devices and subsystems such as homing heads or seekers or tracking kits and control fin drives. The devices used within this laboratory include the popular measuring instruments (multimeter, spectrum analyzer, oscilloscope and function generator) and the inertial instruments such as the gyroscopes and accelerometers. The paper addresses the test procedure and performance parameters for the inertial instruments. This strategy allows more flexible and better learning experiences with deep understanding for the students and/or researchers.

Keywords: Guidance and Control, Navigation, Inertial Sensors, System Identification, Signal Processing

1- Introduction

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papers concerning the laboratories of different disciplines; see for example [2-4, 10-15, 21-26, 28-32]. However, our conferences seem to lack this approach and have no the tendency to motivate the high power within each of us. In addition, the field of the author's interest which is the guidance, navigation and control is the nerve of any nation to enlarge its capability for protection against any offensive intent. This field will continue to have added importance from day to day and their system's applications continue to take on an ever-increasing importance. Therefore, the paper has two objectives: first is to highlight the necessity of guidance, navigation, control , signal processing and image processing and second is to utilize the advances in computer and control technology for establishing a laboratory covering the different topics or points constituting this field. In the development of a missile system, experts must be working on each component, trying to make that component do its assigned task with just as little weight, size or space, power, and cost as possible and yet with enough reliability for the purpose.

The guidance engineer must grasp a sound understanding and knowledge of the fundamental principles involved in missile design. In addition, he should have a broader view and hence a better appreciation and feeling of the various design aspects in order to achieve a more efficient design. However, this field is usually facing many challenges such as information availability, system design complexity, and ever-increasing requirements with the possibility of unstable or tolerable environments. This objective of good understanding and system feeling necessitates the availability of an appropriate laboratory for conducting different levels of assignments with the different subsystems constituting the guided missile system. Fortunately the present advances in computer and control technology facilitates this objective and consequently this paper was motivated. The approach is to simulate the system either using software or hybrid software with hardware and then analyze its performance. The simulation process and analysis is discussed briefly in the next section of this paper.

2- Missile Simulation and Analysis

2.1 Methods of Missile Motion Investigation

The guided missile motion can be investigated utilizing one of three approaches: Kinematic methods, Simplified dynamic methods and Dynamic methods. In **kinematic methods** the missile is assumed mass-less point and the equations describing its motion are derived without considering the causes to this motion. Utilizing these methods, it is possible to determine the shape of trajectories and the necessary maneuverability of the missile under the assumption that the velocity of the missile is a known function of time. The **simplified dynamic methods** continuously determine the missile velocity along the concrete trajectory. The common feature here is the neglection of the missile rotary motion around its c.g. (the missile is considered as a mass point). These methods have two variants according to what extent the constriction limiting the motion of the guided missile is satisfied. Finally, the **dynamic methods** which apply with full consideration of dynamic properties of the guided missile and control system. In these methods the whole set of equations describing the missile motion including the equations representing the deviations of control fins, called law of control, are used. The law of control is a set of equations determining the deviations of control fins in dependence on signals produced by the control system and determining the dependence of these signals on motion parameters of the missile and target.

2.2 Simulation and Computation

The first problem faced by the designer of a missile guidance system is that of translating the missile tactical problem into specifications for the guidance system design. A synthesis of the proposed system must be made in order to develop the specifications at a time when only the mathematical expressions which govern the behavior are known, and those are known only approximately. Simulation of the system by analogue and/or digital computers is employed as an aid to the processes of missile design. Complete simulation may give a way to partial simulation, as the design progresses, by substituting some of the completed elements of the system for the mathematical expressions previously employed. Therefore, simulation is a continuing aid to designer throughout the duration of the design program. When the guidance system has been developed/designed, the behavior of different equipments is proved by flight tests from which the data are collected utilizing telemetry systems. These data are then evaluated to furnish an additional aid to the designer of the guidance system. This evaluation and redesign processes are carried out utilizing the simulation on computers. Therefore, the computers are considered main components of the missile guidance system during design and implementation processes.

Simulation is a process of imitating the behavior of the actual missile system by a set of physical equations governing the guided missile motion and solving on computers utilizing any of the known and available numerical methods yielding a flexible and reliable tool for system design and analysis. The equations governing the behavior of the guided missile constitute a set of complicated differential equations involving nonlinearities of many kinds. These nonlinearities may stem from the aerodynamic behavior or from such mechanical effects as limiting, dead-bands, backlash, and hysteresis effects. Therefore, the solution of these equations can be carried out either through:

1. reducing the complexities by considering some simplifying assumptions, keeping in mind that the simplified should be sufficiently similar to the full system for useful conclusions to be drawn from this simplified system, or
2. utilizing the great developments in computation means, such as small size, high speed, huge amount of data manipulation, etc.

As a consequence of the enormous advances in computer technology, **the hardware in the loop tests** are one form of evaluating the performance of a guided missile during the design and analysis phase. This form of test establishes an accurate estimate of the missile performance. For example, an inertial navigation system (INS), or just any of the inertial sensors, is mounted on a test rig, known as multi-axis turn-table. This turn table reproduces accurately the angular motions that the system would experience during its operational life, such as a flight in a ballistic/cruise missile. The output signals from the device under test (INS or inertial sensor) are connected through a suitable interface to a computer simulating the motion and performance of the vehicle. In addition, the mathematical model in the computer generates the signals that control the turn-table, hence a simulation operating in real time, using actual hardware can be configured to enable realistic performance assessments to be established for complex systems operating in various flight regimes or conditions.

The simulation of a guided missile system can be carried out using different methods depending upon stages of the simulation and on the complications encountered as follows:

1. **Analytic methods**: in which the behavior of the servos and airframe in the complete loop is approximated by linear differential equations with constant coefficients. These equations are solved analytically to yield the desired solution.

2. **Numerical methods**: in which the equations representing the guided missile motion contain some nonlinearities such that the analytic methods can not deal with it. The solution is carried out using hand computation.
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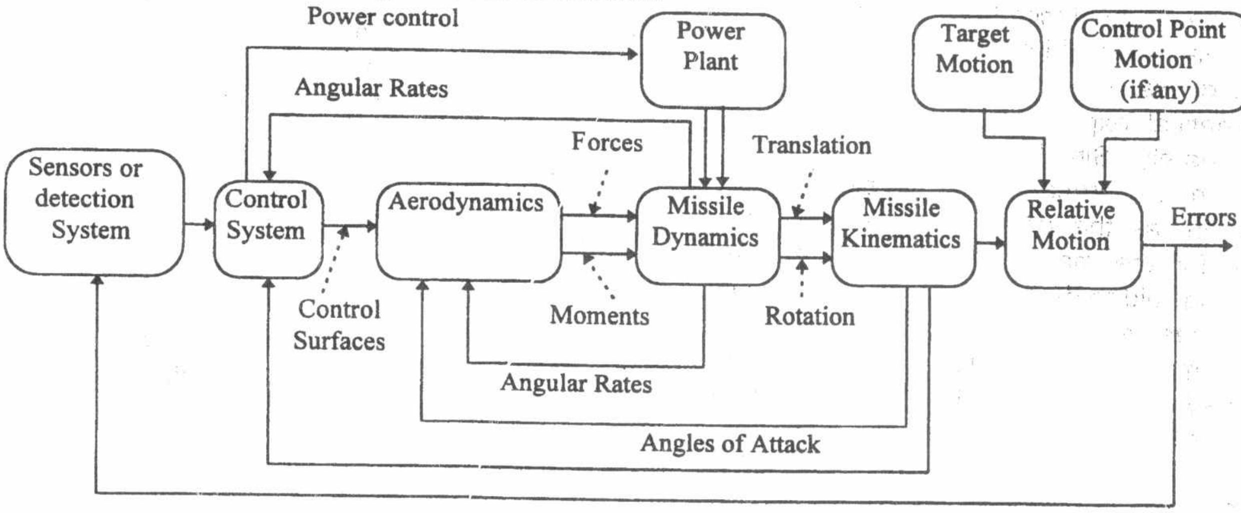

Fig. 1: Simulation of missile muidance system

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Due to the objective of this laboratory, it should cover all of the subsystems constituting any guided missile system with the possibility to emulate flight environments as possible with the pertinent random or stochastic characteristics. Thus, using such a laboratory it will be possible to carry out measurement, test and analysis for the following guidance and navigation elements or subsystems:

1. Tracking system with different capabilities
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Thus, the laboratory structure simulating the guidance process in a missile can be thought as shown in Fig. 2 which constitutes the following elements:

1. Programmable (computer controlled) test and measuring instruments including multimeter, function generator, oscilloscope and spectrum analyzer. These instruments are utilized for testing and analyzing the performance of inertial sensors and of the tracking and guidance loops.

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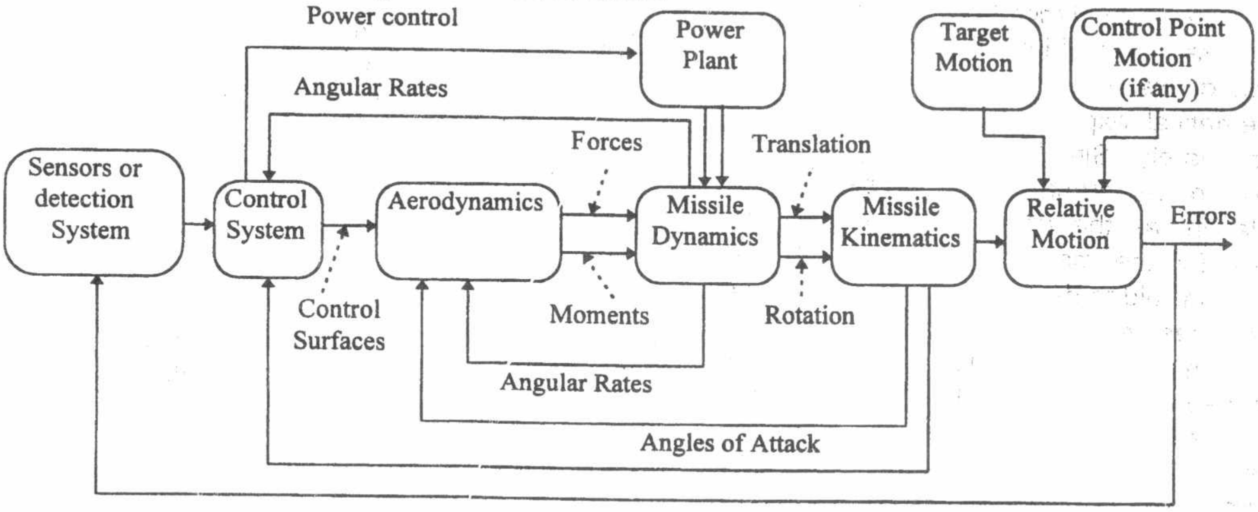

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Thus, the laboratory structure simulating the guidance process in a missile can be thought as shown in Fig. 2 which constitutes the following elements:

1. Programmable (computer controlled) test and measuring instruments including multimeter, function generator, oscilloscope and spectrum analyzer. These instruments are utilized for testing and analyzing the performance of inertial sensors and of the tracking and guidance loops.

2. Inertial sensors such as: free gyroscopes, rate gyroscopes, accelerometers and resolvers.
3. Servo systems with servomotors or actuators (electric, hydraulic and pneumatic) having controlled inertial loads including the various types of supply. They should be interfaced with the control computer to simulate the control fin drive as near to the real as possible and to be used in the test, design and analysis of autopilots.
4. Targets' emulators (IR, Laser or Radio) to be used in the test and analysis of different tracking and guidance systems. In addition, an appropriate x-y positioner on which these target emulators are to be fixed for simulating different controlled target trajectories.
5. Computer controlled turn-table (single axis, two axis and three or five axis) to be used in the simulation and analysis of different tracking, guidance and control systems. In addition, it can be used with the design and analysis of autopilots. This table is used to install or mount the missile seeker and/or inertial sensors under test or within the tracking and guidance loops.
6. Control computer with the necessary interfacing software and hardware to carry out the experiments in a test or in a real time environments.
7. Educational kits for homing heads (IR, Laser, Radio) or the detectors for which the gimbals can be any of the turn-tables and the tracking loop done either by software or hardware.

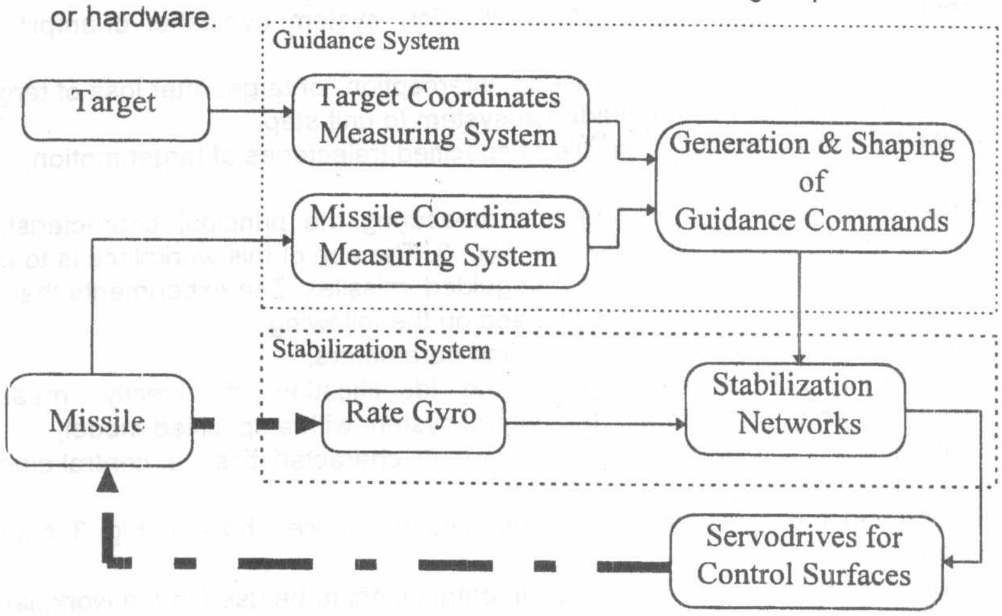

Fig.2: Block diagram for the control system (autopilot) of a guided missile

As clear from Fig. 2, the hardware in the loop tests are one form of evaluating the performance of a guided missile during the design and analysis phase. This form of test establishes an accurate estimate of the missile performance utilizing the capabilities of present computers with data acquisition facilities working in the real-time situation. For example, a fin control drive can be emulated by an appropriate servo system to which the input command is the output from the guidance system simulator. In this subsystem, the hinge moment and environmental loading of the fin can be emulated with appropriate friction and damping elements. Using the actual hardware, it can be configured to enable realistic performance assessments to be established for complex systems operating in various flight regimes or conditions.

The control computer has to contain all the necessary storage media and the data acquisition and interfacing cards to acquire different signals and control the operation of different parts of the system. In addition, the processor should be capable of running the appropriate software in real time operation or environment. The software application should be windows-based for allowing the experiments to be programmed, saved and executed whenever needed during the learning and/or training exercises.

4- Measurement of G. M. Control Systems Characteristics

The guided missile (G.M.) complex control system, from the viewpoint of technical implementation, represents rather intricate technical equipment. That is why is applicable to perform experimental measurements and processing of the results in the following procedure:

1. measurement of impulse sequence and frequency characteristics of the central element of the stabilization system (stabilization networks), calculation of parameters of transfer function in each channel,
2. measurement of autocorrelation sequence and spectral power density of the central element of stabilization system (stabilization networks), estimation of parameters of transfer function in each channel.
3. measurement of degree of stability of stabilization system, evaluation of amplitude and phase security or margin in each channel.
4. evaluation of missile maneuver at reverse interception of target after loss of target with specified time interval, response of guidance system to unit step.
5. evaluation of target missing by the missile at specified trajectories of target motion.

A design of the workplace for modeling and measuring the principal characteristics of a guided missile control systems is shown in Fig. 3. The aim of this workplace is to perform experiments with the control systems of the guided missiles. The experiments that can be performed on the proposed workplace are focused on the following :

1. Detection of measurable characteristics and parameters,
2. Measurement of accessible signals and identification of directly measurable characteristics and parameters of the control system with a specified model,
3. Modeling of control system decisive elements characteristics, i.e. central element of stabilization system and guidance system.

Therefore, the principal of functioning the proposed workplace, shown in Fig. 3, consists of the following parts:

1. Control system (Autopilot) which is an experimental object to be used in the workplace,
2. Programmable digital multimeter is intended for measuring the principal electrical values within the servo-drive of the control surfaces. The measurement is carried out automatically through the data bus.
3. Programmable function generator produces testing signals for the control system. It simulates the target and missile motion for testing the guidance system and it simulates the shape of interfering moments on the rocket flight trajectory for testing the stabilization system. The generation of testing signals is program controlled by means of the control computer bus.
4. The interface enables the transfer of data between the control computer, measuring instruments, sensors, control drive and the turn-table.
5. Simulation and control computer is intended for implementation of simulation, control, and data processing programs.

Within this workplace, it is necessary to model the control system characteristics which can be considered as a qualitative estimation of guidance system parameters and estimation of stabilization system parameters with respect to the quality of the missile homing on the target. Real technical systems are replaced by mathematical model in the form of difference equations which are solved by a suitable numerical method of integration. The input and output are implemented by means of input port equipped with A-D converter and output port equipped with D-A converter.

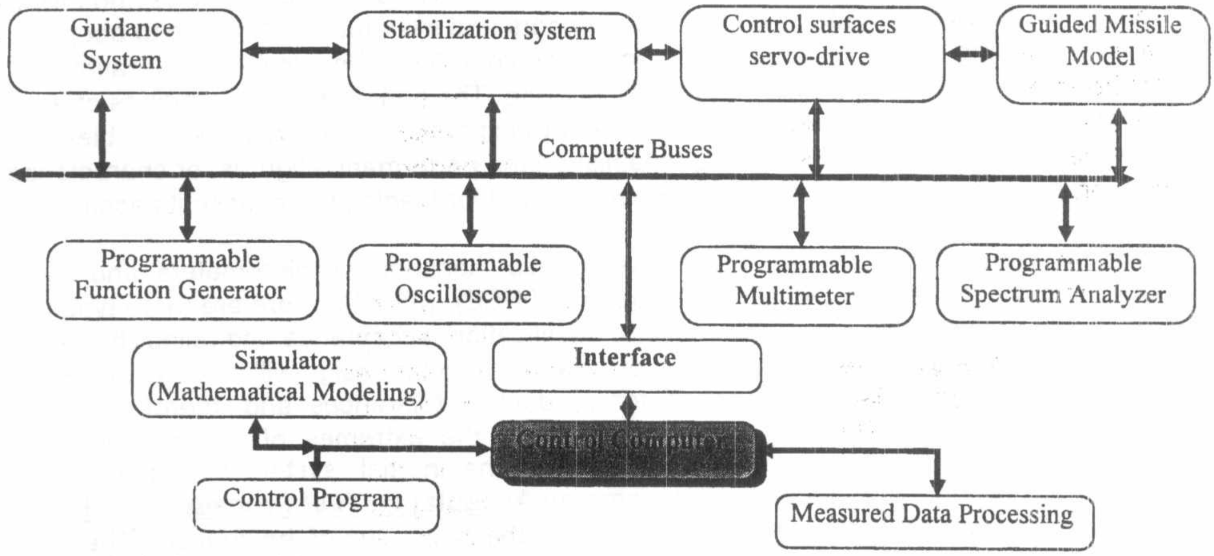

Fig. 3: Block diagram of the workplace for modeling and measuring the control system characteristics

One of the main elements constituting the missile control system is the **control fin drive**. The control fin drive characteristics can be measured through experiments which carried out using hardware or software as part of the guidance process simulation. The actuators may be one or mix of electric, pneumatic or hydraulic systems with the necessary power supply. These actuators are driven by the missile autopilot (a computer model) and the aerodynamic loads on them can be computed and fed into torquers to load the control surfaces correctly. In addition, the guidance simulator software can calculate the expected body rates and aerodynamic forces resulting from the application of the demands to the actuators. All these loads and responses can be calculated to overcome the complexity of including aerodynamics in such a laboratory and then fed into the guidance model as if they had arisen from a real airframe. Using windows based software the actuators' responses and fin deflections can be shown on the monitor as happen with the hardware instrumentation. In addition, this software should enable the user to program, save and execute experiments for each type of actuators leading to different designs with the appropriate analysis and investigations. Thus, the control fin drive experiments can include the following:

1. Measuring the fin control drive characteristics
2. Design the necessary controller/compensator for different fin dynamics (loading and hinge moment) allowing the possibility of using different design approaches
3. Using the feedback sensors in a closed loop fin servo.
4. Using the fin control drive with a 6DOF guidance algorithm to justify the hardware in loop and autopilot designs.

To carry out these experiments, they should be controlled via the control computer and include the following elements:

1. Servo motors with the necessary power supplies and adjustable hinge moment with loading
2. Necessary tunable amplifiers (Pre-amplifiers and Power amplifiers)
3. Position and rate feedback sensors (potentiometers and tachogenerators or encoders) and attenuators.

5- Testing of Inertial Sensors

To establish their suitability for a given application, inertial sensors have to go through an evaluation testing process and ensure that they satisfy all the performance requirements of that application. Inertial sensors are usually designed and manufactured to be used within a wide range of applications such as ships, submarines, aircraft, space vehicles and missiles. In addition, the environments in which these sensors and systems are required to operate varies widely. Testing and calibration methods should reflect the type of application and the environment in which they are required to operate. The behavior or performance of an inertial sensor can be represented mathematically with expressions having some variables obtained from testing and calibration. Having established the performance figures, or characterized the sensor, any systematic errors may be compensated for leading to enhance its accuracy.

This section describes the testing of inertial sensors, accelerometers and gyros, for conformance to the specifications standards (IEEE) [35-44]. There are three types of tests commonly carried out on these sensors: qualification, acceptance and reliability tests [1,17]. **Qualification tests** are intended to show that a particular design will meet all the customer's requirements with adequate margins for production tolerances and therefore they should precede production. This type of tests concerns the extremes of temperature, vibration, shock, magnetic field and anything else which the inertial system will experience. Then, during production, every sensor will undergo an **Acceptance Test Procedure (ATP)** to check selected parameters and to establish data for the calibration of the sensors. The ATP often consists of bias, scale factor, random drift, and temperature tests in addition to some vibration tests that might be included. Finally, **Reliability Tests** are carried out on a sample of sensors taken at random from the production line in simulated operating conditions to see how long they last. These tests are intended to determine the mean time between failures (MTBF). For example: gyro wheel bearing life tests can verify that bearing fabrication and processing remain under control, ring laser gyros (RLGs) [7,17] will be run to ensure that helium gas seals are reliable, and dynamically tuned gyros (DTGs) may undergo vibration tests for hours to check that flexure processing maintains fatigue life, and so on.

5.1 Testing procedure

The test and investigation procedure may be carried through either static or dynamic methods. In a static test the device is kept fixed and the response to some natural effect or phenomenon is observed. For example, the specific force due to Earth's gravity could be observed or measured with an accelerometer in various orientations. While, in a dynamic test the device under test is moved and the response of the device to that disturbance is monitored and compared with the stimulus. Therefore, the performance of a sensor or a system can characterized through three steps [27] as follows:

1. **Coarse checking** in which a very simple tests are conducted, such as a single stationary position test on a bench, to establish that the device/system response is compatible with the designer's or manufacturer's predictions,
2. **Static testing** in which multi-position tests are conducted to the device/system for deriving its performance parameters, and
3. **Dynamic testing** in which the device is subjected to controlled motion such as angular rotations or linear movements with acceleration. However, this type of test necessitates specialized test equipments such as rate turn-tables or vibrating tables.

During the phase of prototype development or initial research, a testing strategy should be designed to estimate the boundaries of (or envelope for) the device/system performance without increasing the cost and consuming the time for this test. This sensor performance constitutes reliability, mean time between failures, confidence limits, ...etc. Therefore, the testing is also used to grade the sensor performance and hence direct it to the appropriate application.

5.2 Test equipment

Testing of inertial sensors and/or INS necessitates the availability of a specialized laboratory with sophisticated test equipment that can be isolated from shocks, vibrations and other perturbations induced by the local environment. For example, the temperature of the environment can be carefully controlled by utilizing special cabinets that controlled by computers. Therefore, the application of digital computers to the testing process is essential for precise equipment control and data analysis. To enable the application of a given and known stimulus to a sensor/system, and then observe its response for analysis, the testing schedule and procedure must be matched with the application requirements and the testing equipment should have sufficient accuracy and precision. In addition, the data acquisition system and the processing algorithms have to be compatible with the anticipated accuracy of either the sensor or its application. Therefore, the test equipment should be regularly calibrated, otherwise their performance will degrade and contribute error measurements obtained by the sensors under test and leading to erroneous interpretations.

The form of acquired signals is dependent upon the type of sensors, their pick-offs and the nature of any rebalance loops utilized. That is, these signals may be in the form of d.c. current or a.c. current continuous or pulsed type. Therefore, the utilized measuring instruments should be capable of observing any type of signals accurately. For which reason a programmable multi-meter, a programmable oscilloscope and a programmable spectrum analyzer are to be used within the loop of testing procedure, which preferred to be completely computerized, Fig. 4. That is, the control computer can be used to control the motion of test equipment, conduct the required test, collect the required data and analyze to extract any required information. The accuracy of selected instrumentation should match the precision of sensors under test and be capable of observing the various transient effects.

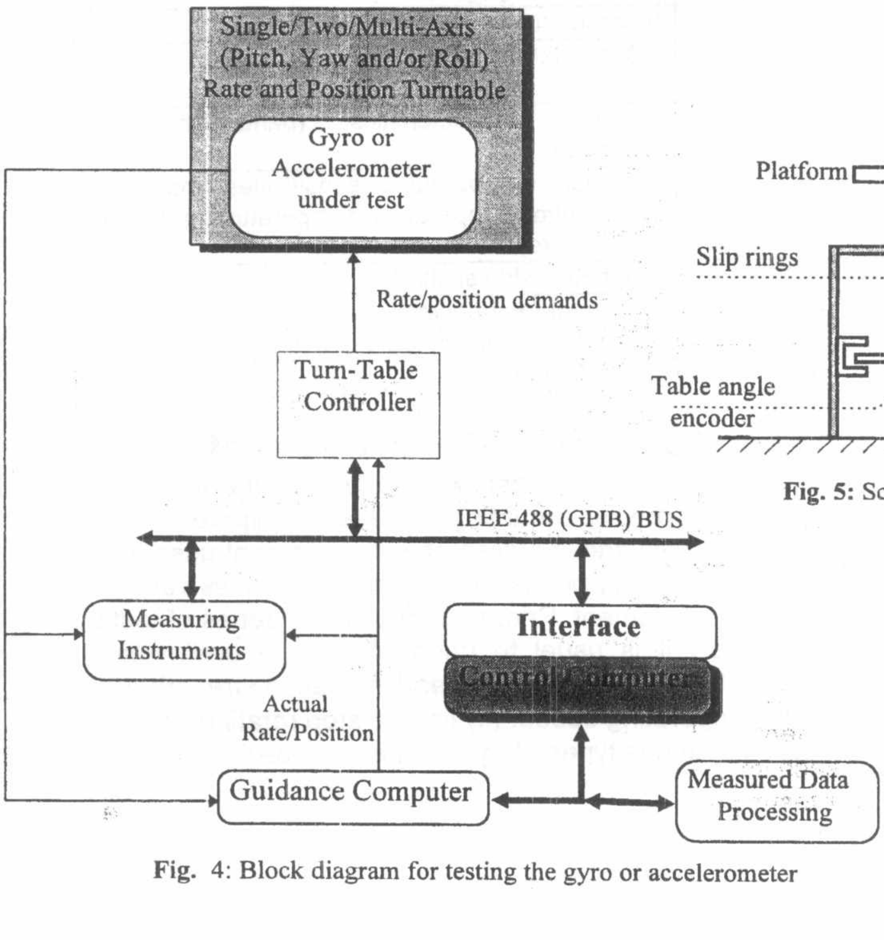

Fig. 4: Block diagram for testing the gyro or accelerometer

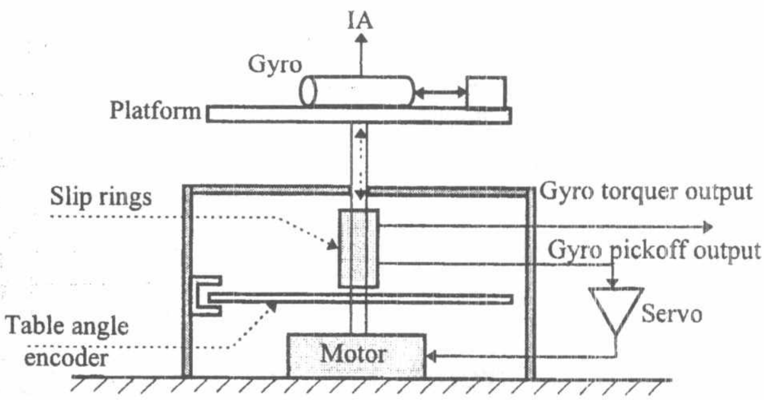

Fig. 5: Schematic diagram for testing the gyro

The servo table or stabilized platform, Fig. 5, is used to determine the gyro torquer linearity with high accuracy through utilizing closed loop control system. The table is rotated by a servo motor when commanded by a servo loop signal with magnitude proportional to its speed and polarity corresponds to the direction of rotation. The servo signal is obtained from the pickoff of a gyro mounted on the table with its input axis (IA) aligned with the table axis. When a current flows in the torquer it causes the gimbal to precess about the output axis (OA) and generates a pickoff signal. This signal causes the table to rotate and accelerates until the gyroscopic torque exactly equals the current induced torque and the gyro pickoff returns to null. Therefore, it needs with it a precise current source and a clock to measure the table rate. Using this table it is possible to determine static and dynamic characteristics of the gyroscopes. i.e. gain coefficient, damping coefficient, own frequency and gyroscope transfer characteristic.

The test stands and rate tables might be equipped with variable temperature enclosures so that sensor parameters can be measured over temperature. In addition, the whole lab should be temperature controlled to a few degrees Celsius and the tables could be equipped with magnetic field coils for checking the magnetic sensitivity. Generally, the test tables are equipped with electronic console containing power supplies, servo loops, output circuits, interfacing networks and the computer on which the data are recorded and processed to extract the appropriate reports about the sensor under test.

5.3 Selection factors for inertial sensors

In applying or selecting inertial sensors, the following performance and environmental factors should be taken into consideration [1, 7, 17, 27, 35-44]:

Operating life (MTBF)	Noise spectrum
Activation time (speed of response)	g-sensitivity
Maximum rate or acceleration	Anisoelasticity (g^2 terms)
Hysteresis	Vibropendulosity
Scale factor (stability, long term, linearity and asymmetry)	OA acceleration sensitivity
Anisoinertia	Transfer characteristics (bandwidth and damping)
Axis alignment stability	Thermal: (temperature sensitivities, maximum and minimum operating temperature, gradients and shocks)
Cross-coupling	Magnetic field sensitivity
Threshold and resolution	Resonant frequencies
Bias	Power consumption (voltages and frequencies)
Drift	Size and mass

5.4 Measurement of gyroscope and accelerometer characteristics

The gyroscopes to be tested are usually mounted in a test fixture, often a cube with very accurately machined faces for achieving very precise mounting in the test equipment. This enables the sensor to be transferred between the various pieces of test equipment used in a test program and maintaining its mounting accuracy precisely. In addition, it allows various designs of sensor to be tested on the same equipment. Prior to conducting a series of tests for evaluating the gyroscope performance, it is usual to undertake some preliminary investigations such as: (1) measurement of electrical resistance and insulation strength, (2) polarity, (4) time for the rotor to reach its operating speed, (4) time to stop rotating and (6) power consumption. Procedures for testing various types of gyroscopes can be found in the IEEE standards [35, 37, 38, 40, 41, 43].

The performance of an accelerometer is usually investigated using a series of static and dynamic test procedures similar to those already described for a gyroscope. However, a reduced scale of testing is required to characterize the performance of the accelerometer. For example, rate table testing is generally unnecessary and the multi-position tests are undertaken using a precision dividing head [27]. This head has a setting accuracy of about one second of arc and enables the sensitive/input axis of an accelerometer to be rotated w.r.t. the gravity vector. Hence, the component of gravity acting along the input axis of the accelerometer may be varied very precisely. Before conducting a series of tests to evaluate the performance of an accelerometer, preliminary tests are usually undertaken to ensure that the accelerometer is functioning as designed by the manufacturer. Typical tests include observation of the output for a short period (10-20 minutes) after switch-on to check the warm-up trends and the determination of the threshold acceleration level which produces and output signal. In addition, small accelerations may be applied along the input axis of the accelerometer using the precision dividing head. The IEEE has issued a number of test procedure documents for testing accelerometers [36, 39, 42, 44].

Briefly, the gyroscope/accelerometer experiments include the following objectives:

1. Measuring the gyro/accelerometer characteristics including most of the parameters described in Section 5.3.
2. Identification of the gyro/accelerometer dynamics (transfer function poles and zeros)
3. Using the gyro and/or accelerometer in a closed loop servo system for stabilization

Therefore, the turn-table should allow the units under test (gyro and/or accelerometer) to be mounted at various positions (aligned to different axes or planes of measurements) on the top of the table. The table controller allows for both manual and remote control of the table position and rate using the control computer with the appropriate software.

6- Measurement of Homing Heads Characterestics

The homing heads are composed of Radio/IR/TV/Laser detector mounted on a set of gimbals for controlling its motion in addition to the appropriate electronics used to process the outputs from the detectors. The processing electronics extract the target flight parameters and apply it to the autopilot for missile guidance and to the seeker controller for closing the tracking loop. As an alternative, a turn table might be used to mount any of the detectors instead of its own gimbals.

6.1 Radio homing head experiments

These experiments concern the performance of radio tracking systems over different ranges of operating frequencies and different techniques. The radio tracking systems may be passive where the seeker tracks the target's own radar emissions, semiactive system in which a radar designator illuminates the target and the seeker tracks or follows the target reflected signals, and active systems in which the tracking system provides its own target illumination and then follows the reflected echo from target. The objectives for these experiments include the following:

- Investigating the performance of Radio homing head in detection of target and target tracking in addition to the ECCM capabilities
- Investigating the performance of robust filters/compensators with the Radio homing head
- Using the Radio homing head with a 2DOF guidance algorithm to justify the hardware in loop and autopilot designs

Due to the high level of precautions and cost needed to limit spurious reflections, an electronic transponder(s) can be used to mimic the echo delays and to feed signals into the receiving electronics at an intermediate stage as if they had come from a real radio seeker or homing head.

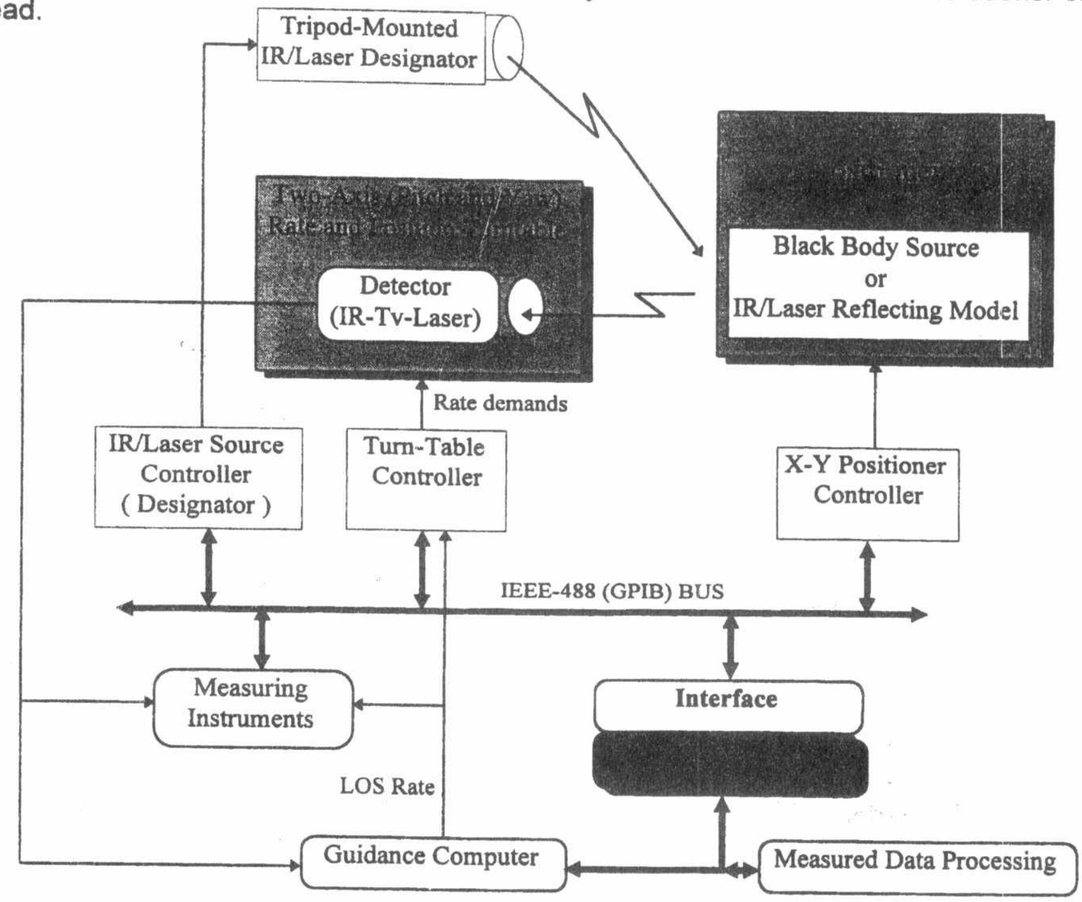

Fig. 6: Block diagram of the IR/TV/Laser tracking system

6.2 IR/TV/Laser homing head experiments

In these experiments the IR/TV homing head (or detector) is mounted on a two-axis rate-position turntable directed towards the X-Y positioner which carry the target emulators (black body source or IR/Laser reflecting model). In case of using a detector instead of the homing head as a whole, the detector is mounted on the inner gimbal of the turntable with the appropriate alignment to carry on accurate measurements leading to the required investigations. Whatever gimbals are going to be used, they have to be controlled manually or through the control computer for design and analysis. This approach allows the control of table motion in open loop or closed loop position/rate configurations. This motion may be programmed via the control computer to investigate the performance of tracking loop as a stand-alone experiment or via the guidance process as a whole. The X-Y positioner carry the target simulators and controlled either manually or remotely via the control computer allowing programmable target trajectories. In case of passive IR detector or seeker, the target is simulated by either a black body source with an adjustable circular aperture or target models that thermally linked to the black body. The black body source can have its own controller allowing its temperature and size to be adjusted either manually or remotely via the control computer. For the semiactive systems or seekers where the target is illuminated by the designator, a suitably reflective model can simulate the target. The test system contains a set of measuring instruments that enables the systems input and output signals to be displayed and captured by standard electrical test equipments. These measuring instruments are controlled by the control computer allowing the experiments to be preprogrammed and executed without the need for a lengthy manual setup of each instrument. The objectives for these experiments include the following:

- Investigating the performance of IR homing head in detection of target and target tracking in addition to the ECCM capabilities
- Investigating the performance of robust filters/compensators with the IR homing head
- Using the IR homing head with a 2DOF guidance algorithm to justify the hardware in loop and autopilot designs

In case of Laser semiactive system, safety issues in relation to the specified laser power and wave length should be taken into consideration for preventing eye damage to the user.

7- GPS and INS Experiments

As a navigational instrument, the inertial navigation system (INS) and/or the global positioning system (GPS) are used to specify the position and different ephemeris data for the host vehicle/table. These data are used for the design and analysis of different types of filters and stay upon their robustness. In addition, the data obtained from the GPS are to compared with the output from the INS and then processed together leading to some investigations upon the use of integrated systems within an aerospace vehicle. This integration has the objective of overcoming the drift of the INS output with time.

The INS experiments comprise three rate gyros and three accelerometers aligned to the axes of an orthogonal inertial reference frame. Depending on the form and nature of the inertial navigation system, it may be appropriate to test either the complete INS or just the inertial measurement unit (IMU) in this laboratory. One of the objectives for this testing is to confirm that the INS fulfill the performance requirements imposed due to a specified application. The system is mounted on a multi-axis table which rotated through a series of controlled and accurately known angles and positioned in different orientations w.r.t. the local gravity vector. Then, the dominant sensor errors may be determined from static measurements of acceleration and turn rate taken in each orientation of the system/unit. That is, the system/unit under test can be placed on a precision three-axis table to which a series of constant rate tests and multi-position tests are conducted to allow the major sources of error to be identified.

Alternatively, the IMU can be tested as a component of a full strapdown INS to estimate the system errors. That is, the estimates made by the navigation system of angular displacement turned through and/or linear acceleration in the navigation reference frame may be used to deduce the various system errors [17, 27]. For example, the unit is made to rotate through a sequence of turns using a two degree-of-freedom table where each turn preceded by a self alignment exercise w.r.t. the navigation frame. Then, the system itself keeps track of the table rotation throughout each revolution. Acceleration components in the navigation reference frame are computed immediately on the completion of each revolution by resolving the measured accelerations into that frame using the computed attitude information. These acceleration components have errors that can be attributed to a combination of acceleration and angular rate measurement errors. The dominant sensor errors can be estimated by rotating the unit through a carefully chosen set of rotations [17, 27]. The IMU or the INS can be investigated through the following tests:

1. **Static acceleration test** in which the INS is mounted on a level table with each sensitive axis pointing alternatively up an down (six position test) and consequently it is possible to estimate the accelerometer biases, scale factor errors and the sensitive axis misalignments w.r.t. a set of datum mounting faces. These estimates can be computed by summing and differencing various combinations of acccelerometer measurements.
2. **Static rate test** in which the INS is mounted on a level table with each sensitive axis pointing alternatively up an down (six position test) and then the angular rate measurements provided by the system are monitored for a pre-defined period of time.

Using a number of different orientations, it is possible to estimate the gyroscope fixed biases and g-dependent biases through summing and differencing various combinations of gyro measurements.

3. **Angle test** in which the INS is mounted on a precision multi-position table that can be rotated through accurately known angles. These angles are compared with angles' estimates obtained by integrating the rate outputs from the gyroscopes to yield estimates of the various errors in the gyroscopic measurements. For example, turning the table clockwise and anti-clockwise through the same angle can yield estimates of gyroscope to case mounting error along with gyroscope biases and scale factor errors.
4. **INS multi-position test** in which the INS is mounted on a turntable that rotated through a set of test rotations allowing to extract estimates of the most dominant sensor errors associated with a strapdown system containing conventional gyroscopes. Many different linear combinations of the gyroscope's fixed biases, g-dependent errors and mounting misalignments can be made observable through this test.

These tests can be carried out recursively through using the error estimates from one test to update or correct the error model used in subsequent tests. To extract estimates of the system errors, various signal processing techniques (least squares, kalman filters,...etc.) can be utilized.

The GPS experiments are essentially comprise a GPS receiver feeding a local control computer which can be to be used with students for practising programming routes, waypoints, and navigational procedures. A second objective is to make comparisons between a (drifting) inertial system and a surveyed (noisy) GPS system in order to improve the accuracy. By using a precisely known geographical location to correct for residual errors in the GPS system, the GPS outputs can be used to correct the drift errors in the INS mounted on the table [16, 27].

The GPS kit should provide the following data:

Current position in central frame of reference and other references

- Pseudo-ranges of current satellites in the current horizon
- The GPS time
- Ephemeris data
- Multiple channel i.e. parallel data process/transfer and no time sharing
- Navigation message including:

ionospheric delay, ephemeris data, satellite identification number and so on.

8- Conclusions

This paper gave a systematic and concise explanation for a laboratory concerning the guidance, navigation, control and signal processing. This type of laboratories could be appropriate for undergraduate and graduate students as well as those practicing and searching and/or manufacturing in the field. The paper offered a structure for the laboratory including different devices and subsystems such as homing heads or seekers or tracking kits and control fin drives in addition to inertial sensors. The devices used within this laboratory include the popular measuring instruments (multimeter, spectrum analyzer, oscilloscope and function generator) and the inertial instruments such as the gyroscopes and accelerometers. The paper gave layout for each experiment concerning the different subsystems constituting a guided missile system and addressed the test procedure and performance parameters for the inertial instruments. This strategy allows more flexible and better learning experiences with deep understanding for the students and/or researchers. In addition, it facilitates the process of design and analysis of system performance within different and changeable environments. Thus, the paper could help the guidance engineer to grasp a sound understanding and knowledge of the fundamental principles involved in simulating a missile guidance, design and analysis. The point to be remembered here is that such laboratory with the given structure should be utilized and the procedure followed at the instant of beginning to manufacture a new guided weapon system until the flight tests success.

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