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Control System Design and Development of DSP based Controller for Servo Payload System

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***Abstract*—Under the present work efforts were made to carryout design of a closed loop Control System for stabilization of a weapon mounted on a combat vehicle. The whole system is an electromechanical system, as the name suggests it is a combination of electronics and mechanical mechanisms. The basic components of any electromechanical system are gimbals and gyros. A typical inertial stabilization platform used to stabilize payload or sensor LOS uses an Electromechanical Assembly acting as the physical connection between the payload (weapon module or optical sensor) and host vehicle. The sensor or the optical components of the sensor are rotated by the gimbals provided by the ISP electromechanical assembly. A control system is designed to manipulate the electromechanical assembly and hence payload to provide necessary stabilization. The control system has at least three functions, namely, stabilizing the LOS minimizing disturbances, tracking to follow target and maintaining LOS orientation so that the location of the target can be determined in an appropriate coordinate system.**

***Index Terms*—DSP, ISP, LOS, Payload, Simulink, VisSim.**

I. Introduction

The objective when designing a Stabilization/tracking system is to build an electro mechanical assembly that is capable of compensating for environmental effects, target maneuvers and host vehicle movements/disturbances so that the payload LOS is maintained in a given orientation.

A complete statement of the problem when designing a stabilization/tracking system includes a full description of both the operating environment and the required level of performance.

When designing stabilizing/tracking system, there are numerous design considerations that must be made; each consideration is interrelated to each others and the final choice will result from an iterative tradeoff process among these considerations [1]. For example, two gimbals are sufficient to orient the LOS in any arbitrary direction, but if the payload is intended to produce an image, then the image will rotate around the LOS as non-zero "azimuth" and "elevation" angles are experienced [2]. So, inclusion of additional gimbals will enable the payload carried on the inner gimbal to be isolated from direct contact with environmental disturbances (wind, ice, gun blast etc.) [3].

The LOS control is generally composed of two subsystems: Stabilization subsystem and Tracking subsystem [4].

II. System Description

The system to be modeled is a servo controller system with brushless DC motors as prime mover, gearbox, control handles/ joystick, gyros as inertial sensors and resolvers for tacho feedback from motors. There are two different drives, azimuth drive and elevation drive which consist of mentioned components. The payload shall be mounted on gimbal assembly and has freedom of movement in azimuth as well as elevation. The figures depicting top view and side view of assembly are as shown below.

The sight will be mounted next to payload and the prism of sight has freedom of movement in elevation. The sight shall be fitted on the turret and the gun follows the sight mirror in elevation. The mirror elevation rate command is same as for gun. A resolver shall be fitted on the sight assembly so as to obtain its rate and position. The position error shall be obtained from difference of the two resolver outputs fitted on sight and gun.

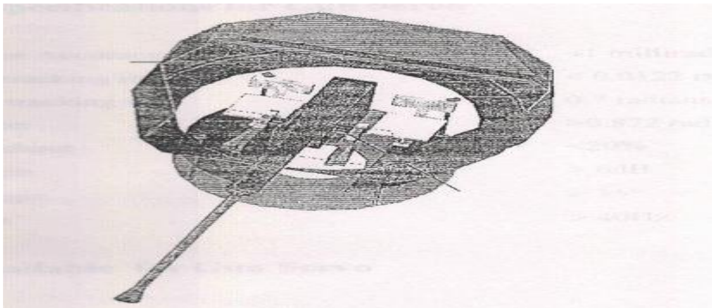

Figure 1: Top View of Stabilization Assembly

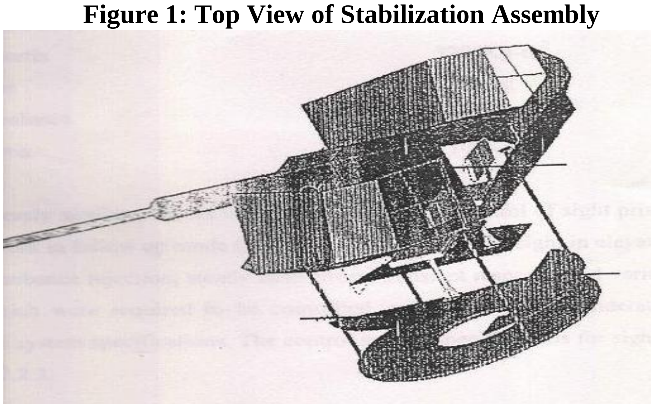

Figure 2: Side View of Stabilization Assembly

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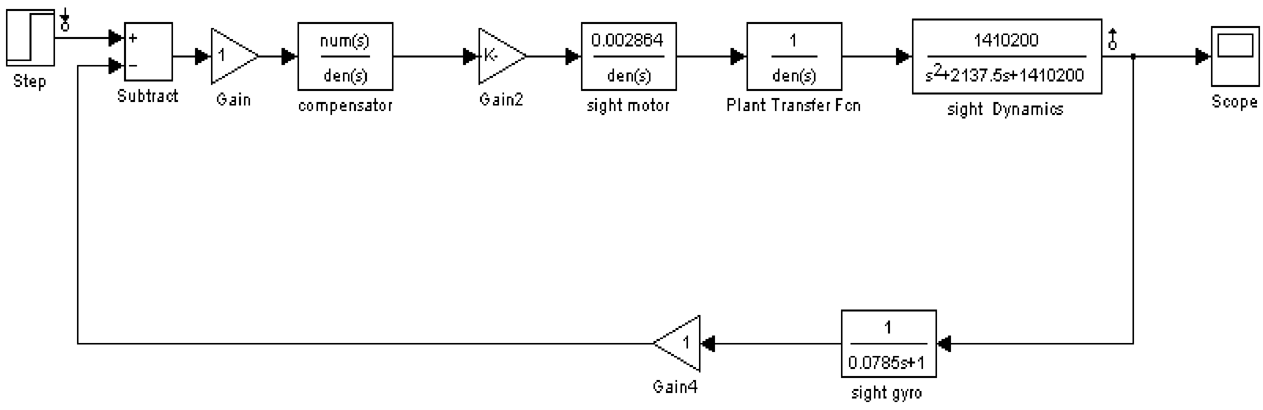

Figure 3: Block Diagram Depiction of Sight Position Loop

It is proposed to model the payload system and sight as described above and to design suitable controller for Azimuth and Elevation loops such that overall system is stable and meets following specifications. The control loop for sight position in the form of block schematics is described above.

Table I. Control Specifications of Payload Servo

Stabilization Accuracy	0.8 milliradians
Drift Rate	< 0.1 milliradians
Minimum tracking rate	0.07deg/sec
Acceleration	50deg/sec^2
Damping	0.2 to 0.5
Gain Margin	> 6dB
Phase Margin	> 35deg
Bandwidth	3-5 Hz

III. System Modeling

After modeling of all system components mathematically the loops were modeled in MATLAB/ SIMULINK and compensator design was carried out.

A compensator is an additional component that is incorporated into a system to equalize or compensate for performance insufficiency. There are several basic types of compensators used in many classical SISO control applications. The majority of these compensators are normally placed in series with the system to be compensated with feedback applied around the combination [5].

Initially we considered the transfer function for lag compensator by default and placed in compensator's block.

After this step we analyzed the model and according to our requirement of bandwidth, gain margin and phase margin, we did loop shaping in LTI viewer to achieve our requirement.

Compensator designed for position loop elevation is as follows-

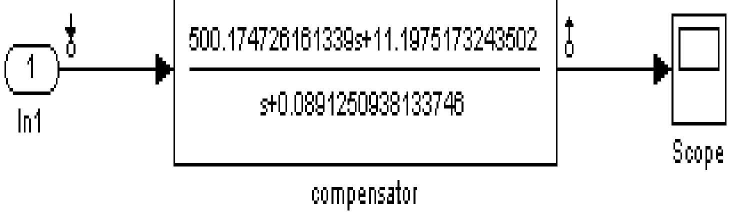

Figure 4: Compensator for Sight Loop

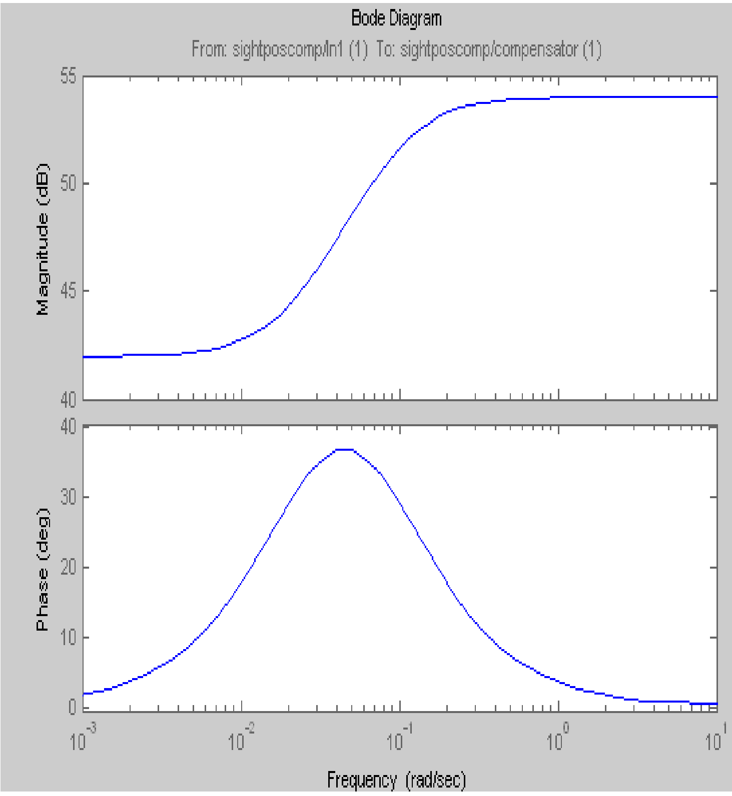

Figure 5: Bode Plot for Compensator of Position Loop Elevation

IV. Software And Hardware Requirements

A. MATLAB Simulink

Simulink describes an environment for multiple domain simulation and Model-Based Design. It allows for simulation,

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automatic code generation and test and verification of embedded systems [6].
Simulink supports a graphical editor, customizable block libraries for modeling and simulating dynamic systems. It is in integration with MATLAB, which allows incorporating MATLAB algorithms into models and exporting simulation results to MATLAB for further analysis.

B. DSP EVM board details

The TMS320LF2407 evaluation module (EVM) lets evaluators examine certain characteristics of the LF2407 digital signal processor to determine if this DSP meets their application requirements as a standalone card. Also, the module provides an excellent platform to develop and run software on the LF2407 family of processors. The LF2407 EVM is shipped with a TMS320LF2407 DSP. The EVM allows full speed verification of LF2407 code. With 544 words of on chip data memory, 128K words of onboard memory, on chip flash Rom, on chip UART, and an MP7680 Digital to Analog Converter. It also provides four expansion connectors to interface to any necessary evaluation circuitry not provided on the as shipped configuration. A number of user interfaces are available to simplify code develop and shorten debugging time

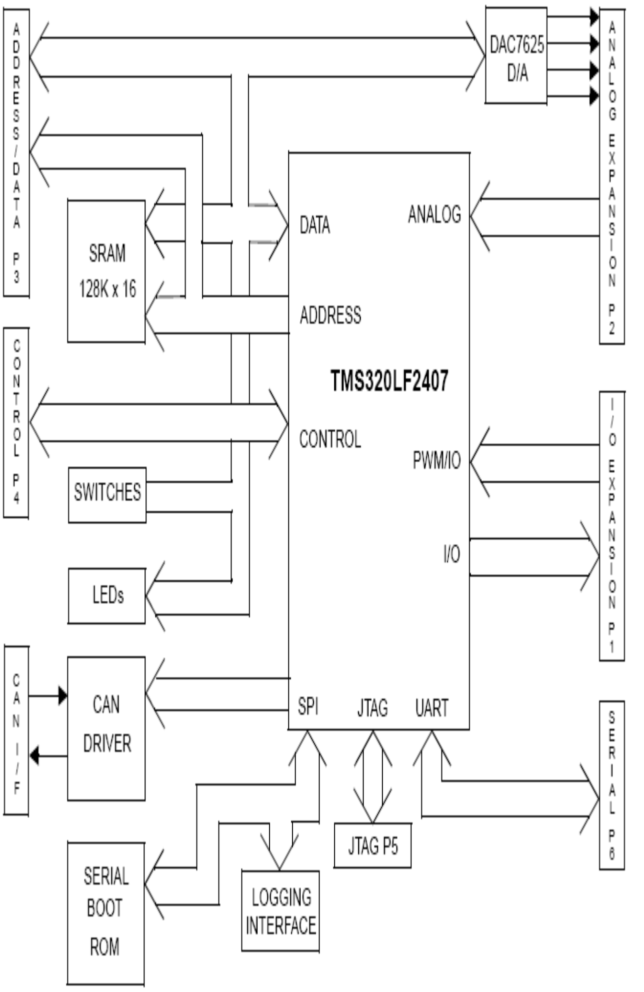

Figure 4: Block diagram of TMS320LF2407 EV

C. Vissim6.0 Software Environment

VisSim is a program based on Windows which allows for the simulation and modeling of complex dynamic systems [7]. VisSim supports an effective dragging and dropping of blocks for block diagram interface along with a powerful mathematical engine. An easy method for constructing, modifying and maintaining complex models is offered by the visual block diagram interface. Quick and accurate solutions for nonlinear, linear discrete time, continuous time, time varying and hybrid design is provided by the mathematical engine. VisSim provides for a fully integrated control system design environment and all simulation and design tasks can be completed without even writing a line of code. Also, shorter learning curve and ease-of-use is provided by Vissim

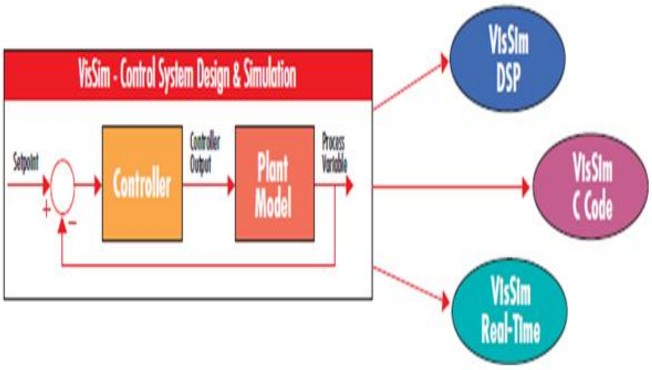

Figure 5: Control System Design Process

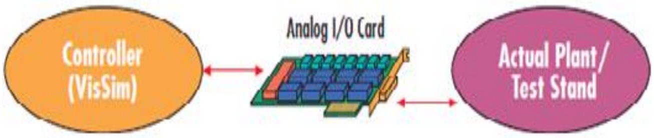

Figure 6: Test Standard

Off-line tuning involves connecting the VisSim plant model to the target control hardware in order to validate the control algorithms (refer to Figure 7). Once the control validation is complete, the control hardware is disconnected from the plant model and connected directly to the real plant which ensures faster, safer and less costly system and equipment ramp-ups. Off-line tuning is useful in the process control industries as it enables validation of controller design without plant or equipment shut down. It is an also important technique for use with expensive/sensitive equipment where a poorly designed and untested controller could result in costly downtime or inefficient performance, damage to the equipment. When in plant or equipment operation, on-line monitoring of the plant-controller closed-loop system is also performed by Vissim.

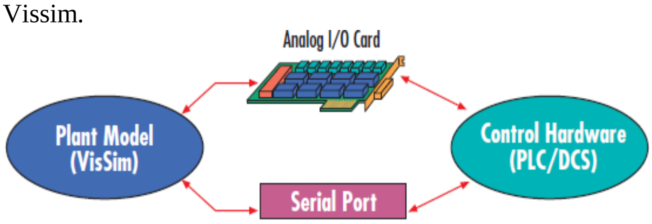

Figure 7: Validation of Control Algorithm

V. Performance Analysis

In system modeling loop equations were derived using control laws and mathematical equations. Also, compensators were designed as per the system requirement. Here in performance analysis, models have been prepared based on derived loop equations and frequency domain & time domain analysis of them have been done. The loops for which these analysis have been done are Motor loop for Azimuth & Elevation, Rate loop Azimuth, Rate loop Elevation, Position Loop Elevation.

Figures 8, 9 and 10 depict the performance of Position Loop.

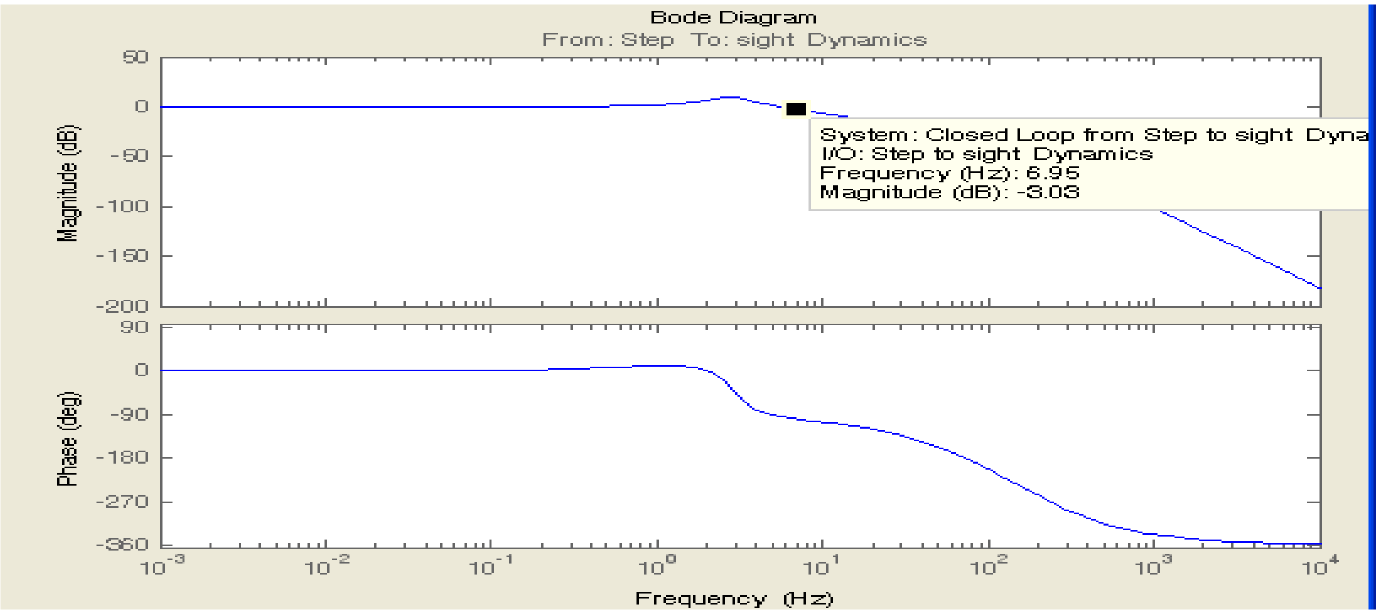

Figure 8: Closed Loop Plot

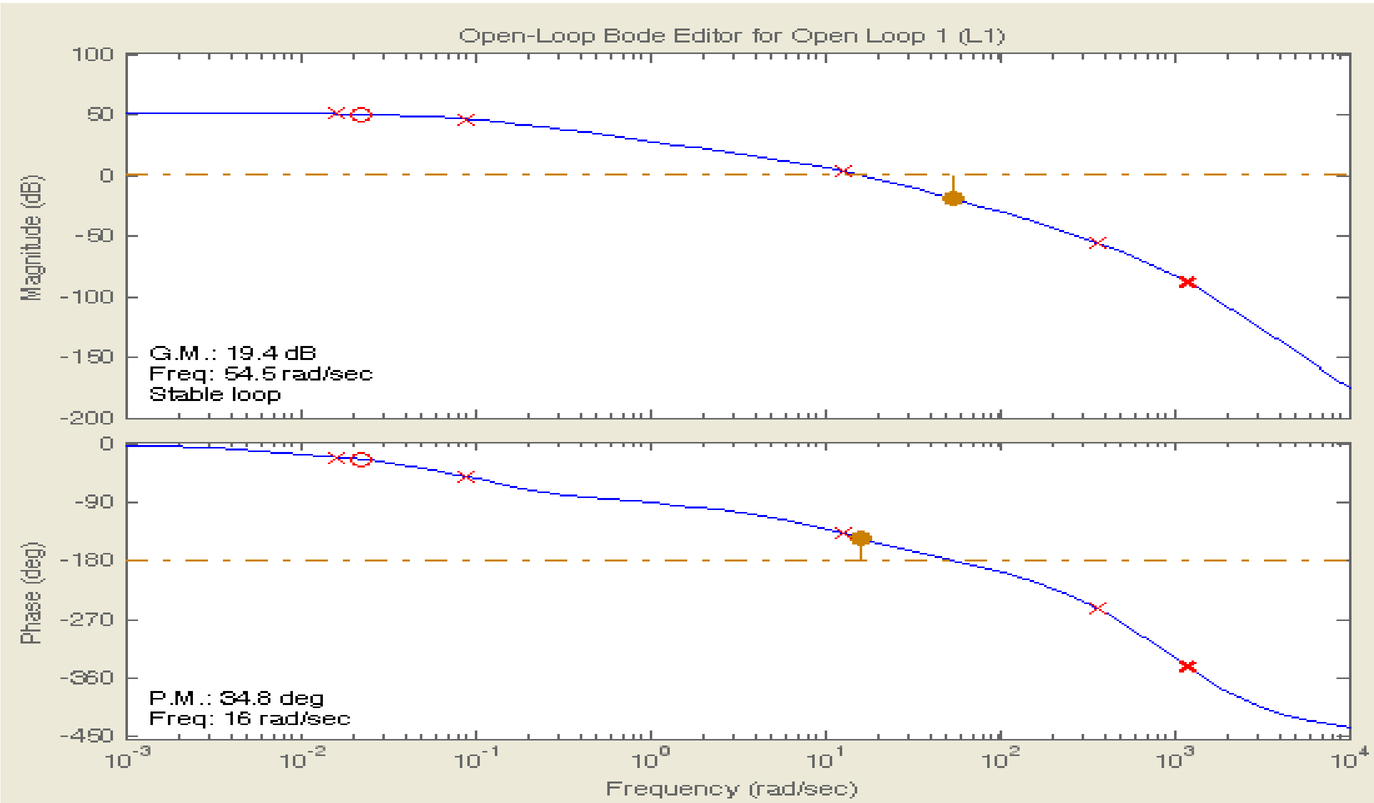

Figure 9: Open Loop Plot

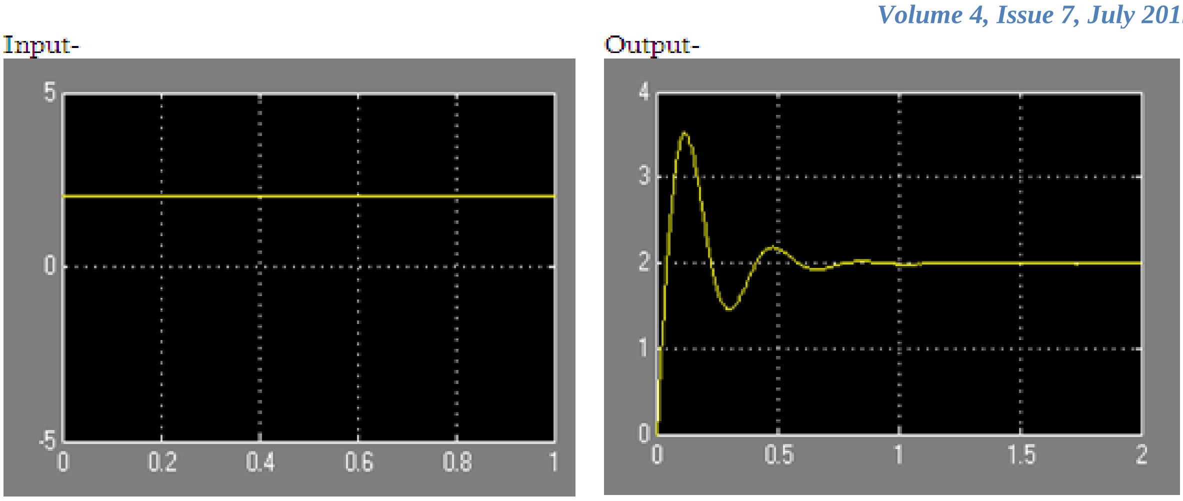

Figure 10: Step Response

VI. Performance Evaluation

The results obtained after the analysis of all models prepared can be summarized as follows:

Table II. Summary of Results

Loop Model	GM (db)	PM (◦)	Bandwidth (Hz)
Motor loop(Elevation + Azimuth)	inf	100	18.9
Elevation Sight Position Loop	19.4	34.8	6.95
Elevation - Motor loop + Rate loop	11.8	70.3	5.02
Azimuth - Motor loop + Rate loop	18.5	69	4.9

Few exercises were performed in VisSim as per the project requirement.

Figure 11 shows the VisSim model prepared for the rate loop Azimuth. The results obtained from this model have been described below the figure.

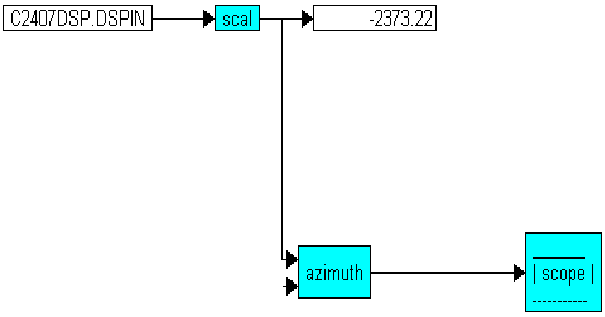

Figure 11: VisSim Model of Rate Loop Azimuth

Here applied voltage was converted into the speed. We applied 0-3.3V as input voltage and certain scaling was done to get following results:

Table III. VisSim Exercise Results

Applied Voltage	Speed Achieved	Direction
0-1.65V	3000-0 rpm	Anticlockwise
1.65-3.3V	0-3000 rpm	Clockwise

VII. Applications

Used to measure the angular position and to measure the inertial rate of rotation of motor.

LOS stabilization/ tracking system have wide application for situations where the orientation of a critical payload must be controlled in a precise manner.

Used for achieving accurate pointing by controlling sensor's LOS.

Used for target tracking.

VIII. Conclusion

Here some of the techniques, basic principles and key design issues related to ISPs used in commercial, military and scientific applications have been introduced and some of the less intuitive effects have been touched that must be dealt with. Close coordination is often required between ISP design and other major subsystems such as optics and primary sensors.

A critical aspect of the ISP design process is the need to understand the dynamic environment. Both the rigid body motion of the host vehicle as well as the frequency spectrum of the rotational and translational motion that the system must operate and the motion of intended targets can impact many decisions in the design process, including the system kinematics, structural design, component selection, and even the basic system configuration.

Control of LOS orientations is a fundamental prerequisite for virtually all dynamic applications in which an optical sensor is used to collect information or obtain images. If an optical sensor is not properly oriented or if the imagery of the sensor is degraded, the sensor is not useful. Whenever the imaging sensor is being carried on a mobile vehicle, or any application in which a dynamic target is to be observed, an ISP is essential.

The fundamental elements of ISPs used to control imaging sensors are electromechanical assemblies, control loops with gyros and trackers as feedback sensors, and auxiliary equipment. Design of stabilization-tracking systems is a multidisciplinary, multistep process, which commences with precise definitions of requirements and a clear understanding of operating environments, followed by detailed design tradeoffs, careful fabrication, system integration, and test. An ISP consisting of gyros, gimbals, motors, and resolvers is at the core of achieving high accuracy.

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