SAGEBRUSH Technology, Inc.

User Manual
Model 20 Pan-Tilt Gimbal
Servomotor Version

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1. PURPOSE AND SCOPE

This document will provide the user with system setup information and will identify the input, output and parameters necessary to operate a Model 20 Servo unit. There are two sections to this document: System setup which includes mechanical considerations, and control specifications. The setup section guides the user through mechanical and electrical specifications and initial turn-on procedures. The control section explains the control philosophy and presents data taken from a unit as verification of the controls.

The serial commands used to communicate with and control the gimbal are described in a separate document, as is the graphical user interface provided with the gimbal on the CD ROM.

1.1. Mechanical Considerations

1.1.1. Payload Orientation

The standard elevation (tilt) range for the Model 20 is +95 to -30 degrees in a polar coordinate system, where the 95° range is up from the center reference switch at the horizontal (0°). This means that the elevation shaft will rotate counter-clock wise to 95° when viewed from the side with the shorter metal cover. The user may install the payload bracket to provide a variety of different ranges, and a payload can be oriented backward or forward on the bracket or shelf. To determine the positive 95 side of the range, make certain that power is off to the unit and turn the payload bracket by hand to both extremes.

CAUTION: Verify that the payload will clear the top of the azimuth drive throughout the +/- ranges before applying power to the unit. Adjust the payload bracket orientation so that the payload clears the azimuth drive (consult the factory for other range-limiting options).

1.2. Definitions

This document defines a software interface protocol and the functions that are available between control units and remote devices as shown in Figure 1.

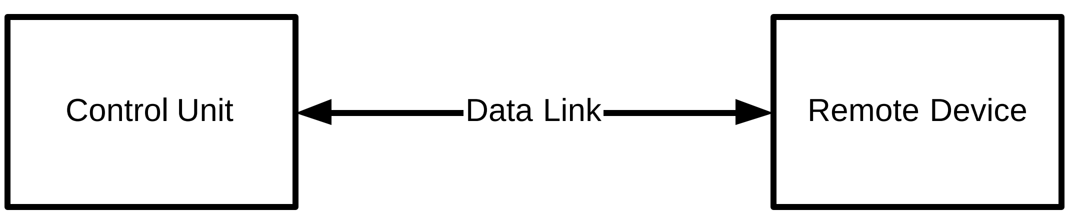

Figure 1. Basic block diagram.

Control Unit A device capable of synthesizing a string of ASCII characters and sending that message to a device to be controlled. The control unit can be a computer-based Display Control Unit (DCU), a separate personal-computer (PC) -based controller, or other device capable of meeting the requirements.

Port An interface on a control unit used to send and receive messages.

Remote Device Model 20 Servo unit.

Address An identifier for either the control unit, the port, or the remote device. Devices must ignore messages not containing their address.

Data Link The data link is the circuitry, software, and media used to transfer messages from a control unit to a remote device. The data link is an RS232 or RS422 (factory configured) protocol which defaults to 9600 baud on startup. The data link is the bridge between the control unit and the device to be controlled, or between control units in a complex system.

Group Control Unit (GCU) A control unit that can be connected through the data link to multiple remote devices using either one port (communications channel) or multiple ports.

Master Control Unit (MCU) In a system with only one control unit, that control unit is called the Master Control Unit. In a system with multiple control units connected through a network, the Master Control Unit is the one designated to have highest priority or supervisory access.

Master/Slave This protocol is defined as a master-slave process. The master (control unit) initiates all communications to the slave (remote device). The slave responds only to the master. This protocol does not allow messages to be sent between slaves. Commands and responses can also be sent between GCUs (including the MCU). Commands and responses are generally sent only between a GCU and devices local to that GCU. This protocol also allows the "pass-through" of commands from one GCU to another GCU and its local devices.

Hexadecimal Values between 0…15 are specified as 0xNN, where N can be 0…9 and A…F.

NIC Acronym for the Non-Implemented Command character (question mark, "?").

1.3. Electrical Inputs

1.3.1. Input Power

The Model 20 Servo has a power input capability of 22 to 36 Volts DC or AC. It is input protected against hooking up power backwards. The red wire should be connected to positive potential and the black wire to the negative potential (ground). The white wire is for case or earth ground. The power supply should be capable of 85 watts minimum output.

1.3.2. Serial Input Connection

The serial input connection consists of a 3 wire implementation of RS-232. The DB-9 connector is wired with the receive line on pin 3 and the transmit line on pin 2. The ground line is on pin 5. This is a standard implementation for direct connection to a Personal Computer.

1.3.3. Joystick Communications (Option)

As an option, the gimbal can be configured for both PC and joystick control. The joystick connection consists of an RS-232 interface using a 5-wire DB9 plug for connection to an industrial mouse. The compatible joystick can be purchased directly from CTI Electronics of Stratford, CT, Part Number M2119-N5-P0111, or supplied by Sagebrush Technology.

1.4. Device Configuration

The pan/tilt gimbal is shipped with the device address set to 1. On power up, the serial input connection is set to a baud rate of 9600.

1.5. Device Orientation

The sign convention used in the control system hardware and software is based upon the encoder counts. The positive direction is the direction of increasing encoder counts. The negative direction is the direction of decreasing encoder counts. Relating this convention to directions such as Up/Down and Left/Right or Clockwise/Counterclockwise is arbitrary, and depends upon payload orientation and the observer's reference point with respect to the gimbal.

For the purposes of this document and the user interface software, the following definitions apply:

Elevation: Up and down elevation movements are determined by looking at the single payload side of the elevation shaft (the thinner half of the elevation housing enclosure is the single payload side) with the gimbal base on a table. Looking at the elevation shaft from this reference, the right side (front) of the shaft will rotate up (counterclockwise direction) when the tilt up command is sent. This is the positive elevation direction. The tilt down command rotates the shaft in the clockwise direction and moves the front of the payload down. This is the negative elevation direction.

Azimuth: Clockwise and counterclockwise azimuth movements are determined by looking down the azimuth shaft towards the base of the gimbal. When the gimbal moves counterclockwise (from the reference just defined) the encoder counts are increasing; this is the positive direction in azimuth. Moving in the clockwise direction the encoder counts are decreasing; this is the negative azimuth direction. Right and left direction specifications are defined by observing the gimbal from the front looking towards the payload with the gimbal base on a table. As the gimbal moves, it rotates to the left or the right from this reference point. Rotating to the right from this reference point corresponds to the counterclockwise or positive direction. Rotating to the left corresponds to the clockwise or negative direction.

1.6. Joystick Communications (Option)

The optional joystick interface allows the user to command the gimbal without using a PC. The joystick operates on a serial interface and provides azimuth and elevation directional control along with two function buttons.

With the joystick held so that the serial interface cable is pointing away from the user, the positive and negative elevation and azimuth directions with respect to the joystick are as follows:

Elevation: Positive is away from the user, negative is towards the user

Azimuth: Positive is to the left, negative is to the right

With the joystick held so that the serial interface cable is pointing away from the user, the location and operation of the three function buttons are as follows:

Left Button - Joystick Enable

The leftmost button toggles the gimbal operational mode between hold position mode and joystick (rate) mode.

Center Button - Home

The center button drives the gimbal towards the home position (0,0) while the button is held down. The gimbal will resume its previous mode of operation when the button is released, regardless of whether home was reached.

Right Button - Fast Initialization

The right button sends the HV command to the gimbal. This is the first command the gimbal should be sent upon power up.

Note: Before the CTI Industrial Mouse® can be used, the gimbal must recognize that the mouse is attached. This can be accomplished by holding the joystick off center in any direction for a brief moment or by depressing any of the buttons at least two times. This action sends a data stream which alerts the gimbal that the CTI Mouse® has been attached and is ready for use, however, the gimbal will not follow commands sent from the CTI Mouse® until an initialization or fast initialization of the gimbal has been completed (Unless otherwise specified the gimbal will be configured to perform a fast initialization upon power up). If an initialization is not performed on power up (based on a factory configuration variation request) the standard servo system is able to recognize the fast initialization command (right button see above) after it recognizes the mouse. After the initialization is complete, sending the home command (center button) ensures that the gimbal will respond to joystick commands.

1.7. Model 20 Servo Quick Start Guide

The Servo Driven Model 20 has a high torque capability, and therefore MUST be securely mounted to a steady surface to ensure stability. This is especially true for Offset Arm versions. Contact the factory regarding a universal table-top plate.

1.7.1. No Joystick installed

- Install GUI Software on a PC or other Windows System.
- Run the GUI and press CONNECT. The port should be set to 9600 8-N-1. Depending on the GUI used, you may or may not see ‘ACK Timeout’ messages.
- Connect a serial cable from the PC to the Gimbal. Gender and pin-out are configured for a standard straight-through connection to a PC.
- Connect a 24-28V Power Supply to the Gimbal. If the port is configured properly, you should see status messages/position data immediately in either Servo GUI. If you do not see status messages, check port settings and connections.
- The Gimbal should not move, and the motors should remain off. Press the Fast Init [or Verify Home] button. This should be done BEFORE any other button is pressed. After the sequence completes [watch status messages], the Gimbal is now ready to receive Position

or Rate commands. Do NOT send any commands to the Gimbal until AFTER the initialization sequence has completed. To turn the Gimbal motors on, one can press the Home button to send the Gimbal to 0,0 and hold its position there.

1.7.2. Joystick installed

- Connect the industrial mouse Joystick to the serial cable with the mating gender. Note: this is a special purpose pointing device, and is NOT compatible with a PC type Joystick.
- Connect a 24-28V Power Supply to the Gimbal. The Gimbal should not move.
- Press the Right button [with the Joystick cable pointing away from you] to perform a Fast Initialization. This should be done BEFORE any other Joystick button is pressed, and NO other buttons should be pressed until AFTER the sequence completes.
- The Gimbal is now ready to be operated with either the Joystick or a PC. If both a Joystick and a PC are to be used, they should both be connected before power is applied to the Gimbal.

Either quick start method may be used, and either the PC or the joystick may be used to control the Gimbal at any time. Please read the rest of this User Manual regarding Operating Mode considerations.

For those Systems with Integrated Lens Control, the DemoGUI provides Lens Control functionality to get you started controlling your camera lens.

1.7.3. Using The Integrated Lens Control

The Lens Control operates standard motorized zoom and focus lenses with preset feedback such as those made by Rainbow® and Computar®. To determine the correct setting for your lens, there is a simple calibration procedure necessary.

1.7.3.1. Calibration

- Connect the serial cable and power up the Gimbal [Do NOT perform any initialization]
- Run the Demo GUI, Click Connect and observe several status messages appear.
- Select Option->Lens from the menu.
- In the Lens Controls window under Limits, press the GET button. You should see the factory default software limits for this system [typically 10 to 2038].
- Under Zoom, press the IN arrow button until the lens stops moving. Subtract 10 from this number and type that number in the Zoom/MAX field under Limits.
- Press the Zoom OUT button until the lens stops moving. Add 10 to this number and type that number in the Zoom/MIN field under Limits.
- Under Focus repeat this process to determine the MIN and MAX values for the Focus position with the same 10 count margin and type those values for Focus under Limits.
- If you desire a different slew rate for either Zoom or Focus, type those speed numbers in the RATE boxes under Limits. Now press the SET button to save these parameters for the Lens Controller. Note: You can change the speed number at

any time by using Fn or Zn in the SEND box in the main window, where n = the speed number.

- Once this procedure has been successfully completed, the Lens parameters will be retrieved after initialization and will NOT be erased by a Full Initialization command.
- Default parameters may be reset by following steps 1 to 4, and then pressing SET under Limits. This will allow a new lens with a different range of travel to be calibrated.

1.7.3.2. Lens Presets

- The position READ using the GET Preset button will be displayed in the Goto box.
- The position STORED by the SET Preset button will be the values shown in the Zoom and Focus position boxes.
- The position command sent by the GO to Preset button shall be the already STORED position data regardless of what is displayed by the GUI.
- The GUI does not monitor whether the Lens has been disabled by cycling power, therefore the ENABLE/DISABLE button may not display the correct state if power has been turned off and on at the Gimbal but the GUI not closed and restarted. Starting and stopping the gimbal and the GUI at the same time will prevent this. One may also simply click the ENABLE/DISABLE button twice to synchronize it again.

1.7.4. Auxiliary and Camera Relays:

The Auxiliary Relay output is provided to control accessories such as heaters, wipers, etc. It, and the Camera Relay are both controlled by Low-Side driven outputs. Therefore +12V is ALWAYS present on these lines. Proper wiring techniques must be employed to ensure correct operation. Any Standard 12VDC 75mA coil relay may be used for both the Camera and the Auxiliary outputs. Only one relay should be connected to each output.

2. CONTROL SPECIFICATIONS

2.1. MODEL20 Servo Control System

The control system performs closed loop position and rate control for the two axis MODEL20S mount. The gimbal axes are driven by servo motors with a 90:1 gear stage and the gimbal angles are measured with optical encoders mounted on each motor. All servo functions, actuator drive, sensor processing and user interface control are implemented in custom electronics housed in the gimbal mount. A high performance digital processor manages inputs and outputs, computing the servo errors and control actions. Gimbal motion parameters -- travel, rate and acceleration limits -- and pointing -- AZ and EL position and Jog -- commands are configurable through a user interface.

The structure of the control system architecture consists of an inner rate servo surrounded by an outer position servo. A block diagram of the MODEL20S control system is shown in Figure 8. The rate controller stabilizes the gimbal dynamics and provides high bandwidth rejection of gimbal torque disturbances (friction, load imbalance and external inputs). The motor's encoder measurements are filtered into rate signals for closed loop rate control. The controller incorporates integral action to maximize low frequency gain and improve tracking performance. Additional filtering is used to attenuate higher frequency structural dynamicsThe position controller points the gimbal line-of-sight (LOS) based on AZ/EL position commands or AZ/EL move ("joystick-like") commands. The motor encoder measurements are used for closed loop position control. The controller implements time optimal motion profiles based on user specified rate and acceleration constraints. The axes may be controlled independently or synchronized for vector motion.

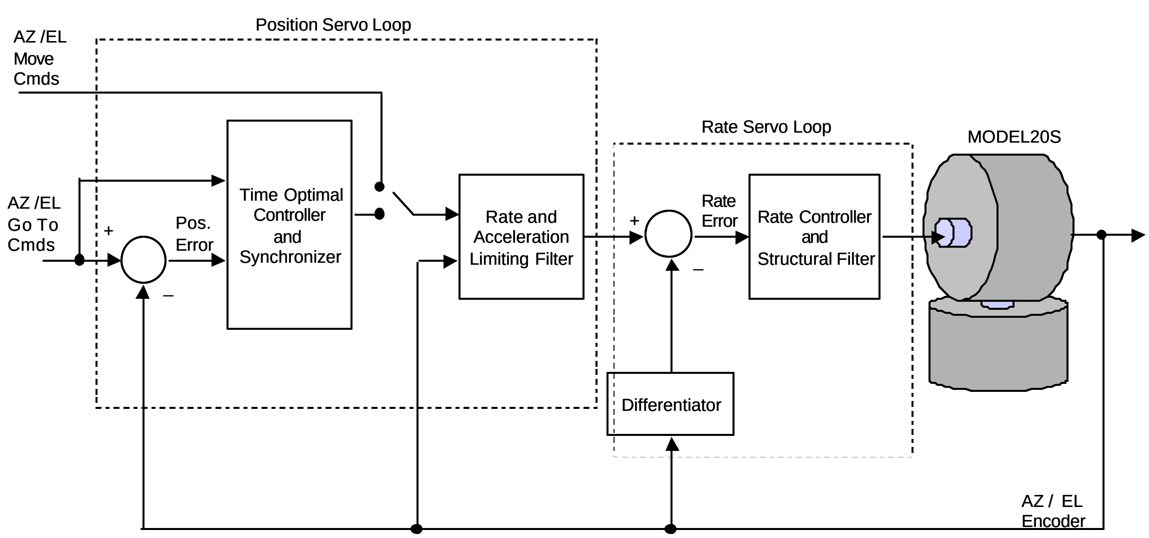

Figure 8: MODEL20S Control System Block Diagram

2.2. Servo Performance and Load Uncertainty

In the current MODEL20S implementation, the inner rate servo is designed for a 10 Hz bandwidth with no load inertia attached. The controller attenuates the effect of high frequency structural dynamics and noise on the servo response. The measured AZ and EL open loop rate loop transfer functions are shown in Figures 9 and 10. Each axis achieves a 10 Hz bandwidth with greater than 40 degrees of phase margin.

As loads are added, the magnitude response will decrease, lowering the servo bandwidth. Additional phase margin will be gained, increasing the loop stability, but the disturbance rejection will be reduced. The maximum load inertia should be limited to .2 Kg-m^2 (20 lb mass with a 6 inch radius). Because of the cascaded control structure, the position loop requires that the rate loop bandwidth be greater than twice the position loop bandwidth (1 Hz) for normal operation. **In general, the mount's gear train and robust controller design minimize the effects on servo performance to load variation**. However, the control software contains a mechanism for adjusting the rate loop gain to normalize the system response for the increased load if required.

Precision servo tuning requires adjusting the rate gain and measuring the resulting servo bandwidth, gain and phase margins. This can be accomplished accurately and efficiently in the laboratory with a frequency analyzer. However, tuning of gimbals in the field is more complicated. **First, it should be determined that the effects of the load are affecting gimbal performance** in terms of positioning accuracy, slew performance or instability (excessive vibration). Then there are two approaches. One is to adjust the gain and observe improved performance characteristics. The other is to record gimbal position data from the mount during pan and tilt move commands. This data needs to be differentiated into rate so that the step response can be tuned to reduce settling time and / or overshoot.

For customers who know their load inertia, a surrogate inertia can be used to tune the servo before shipping. If the load can be provided during integration, the servo can be optimized for higher bandwidths and increased rejection while compensating for structural uncertainty. In future versions of the software, an adaptive algorithm will be implemented to estimate the load inertia in situ and allow the user to tune the servo for optimal performance.

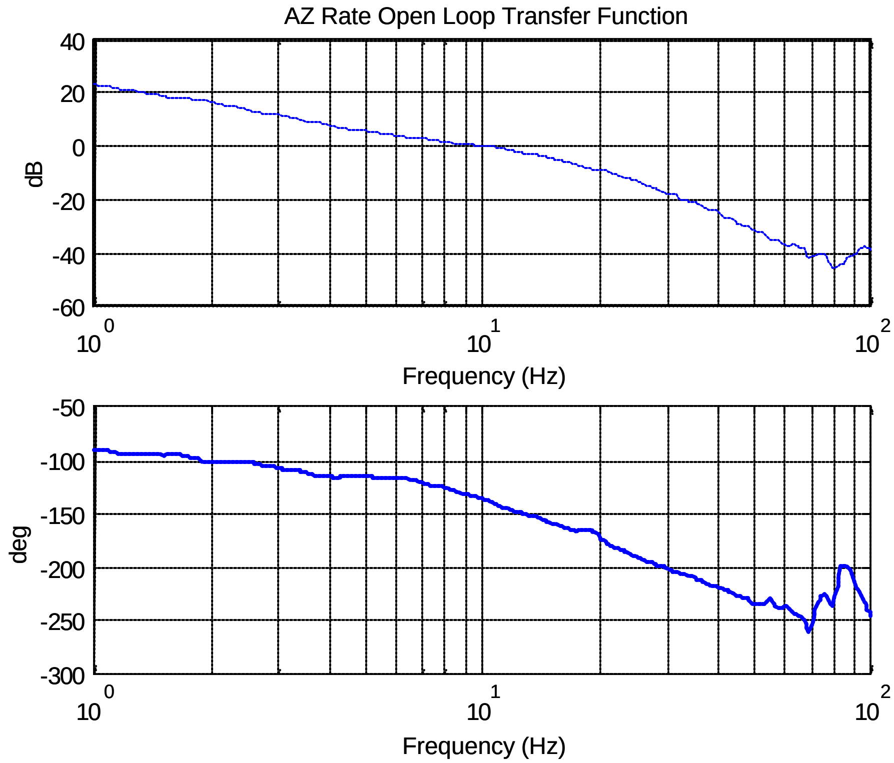

Figure 9: Measured AZ Rate Open Loop Transfer Function

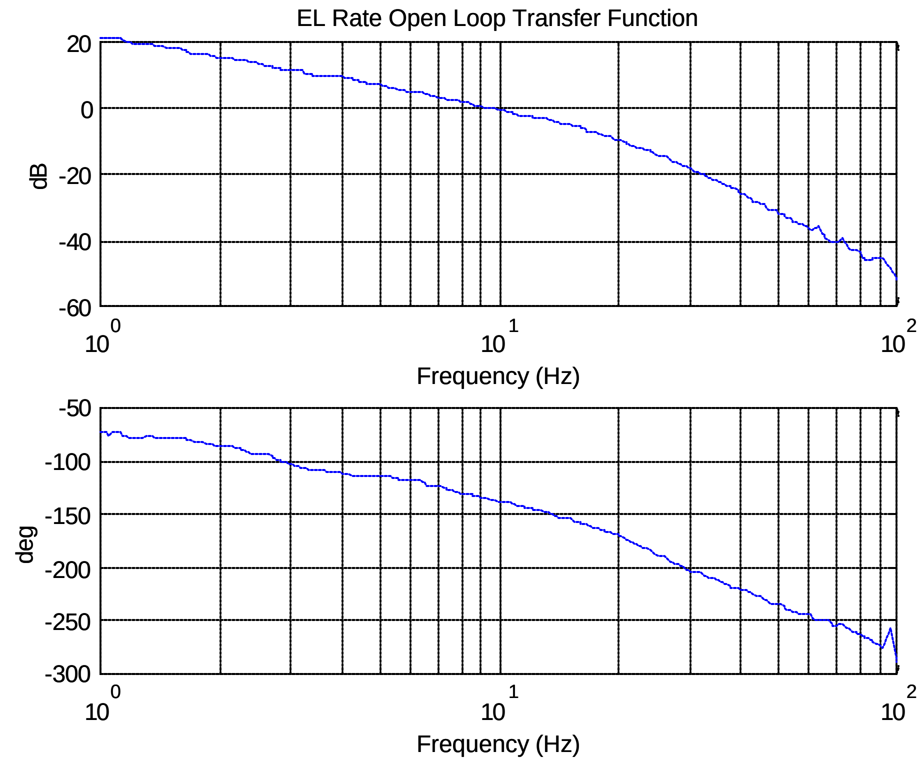

Figure 10: Measured EL Rate Open Loop Transfer Function

2.3. Motion Profiling

The gimbal controller uses a time optimal algorithm when executing position commands. The resulting angular motion resembles an S-curve based on either a trapezoidal or triangular rate profile, depending on the rate limits and command magnitude. The maximum rate and acceleration for any move are configurable through the command set.

The controller implementation limits the servo overshoot below 1% independent of the magnitude of the command. The profile of the minimum time maneuver is determined by the rate and acceleration limits. These limits are configurable from 0.15 °/s to 150 °/s for the rate and 10 °/s^2 to 150 °/s^2 for the acceleration. The upper range on the limits is based on the motor's maximum speed, peak torque and the gear ratio. An example of a gimbal motion profile is illustrated in Figures 12 and 13.

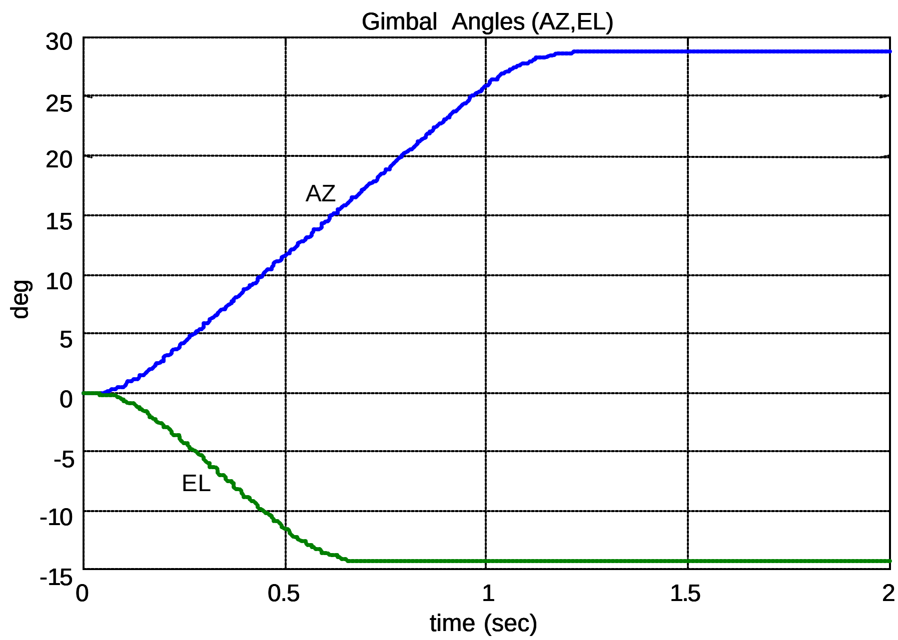

Figure 12: AZ and EL Gimbal Angles During a 28° and 14° Position Maneuver

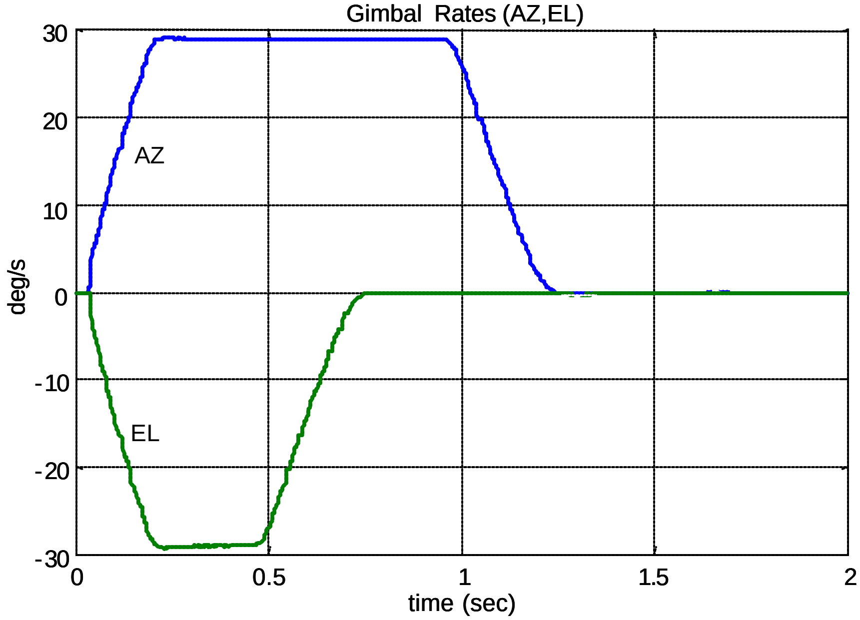

Figure 13: AZ and EL Gimbal Rates During a 28° and 14° Position Maneuver.

The rate limits are set to 28 °/s^2 and the acceleration limits are set to 140 °/s^2.

2.4. Move Commands

Gimbal move commands are implemented with the pan and tilt arrow buttons shown in Figure 14. These commands resemble a virtual joystick causing the gimbal to jog in particular axis at the maximum rate until stopped, a direction changed or a travel limit reached. For best controllability of the gimbal pointing direction, the acceleration limits should be kept high and the rate limits lowered. This will cause the gimbal to stop and start almost immediately during the pan or tilt maneuvers. The software travel limits can be set to reduce the range of gimbal motion during the move operations.

2.5. Vector Moves

The vector move command coordinates the slew motion between the AZ and EL axes. A check box in the gimbal interface software enables this option. For different angular commands in each axis, the slew rates are adjusted to synchronize the slew time for both axes. The gimbal rates and accelerations can be different for each axis without effecting synchronization. In all cases, the longest slew time due to the travel distance or the rate and acceleration limits is used for synchronization. An example of a vector move is illustrated in Figure 15, where servo position errors for different initial offsets converge simultaneously. The gimbal rates shown in Figure 16, autonomously adjust their magnitudes to correct for the different travel inputs and axis accelerations.

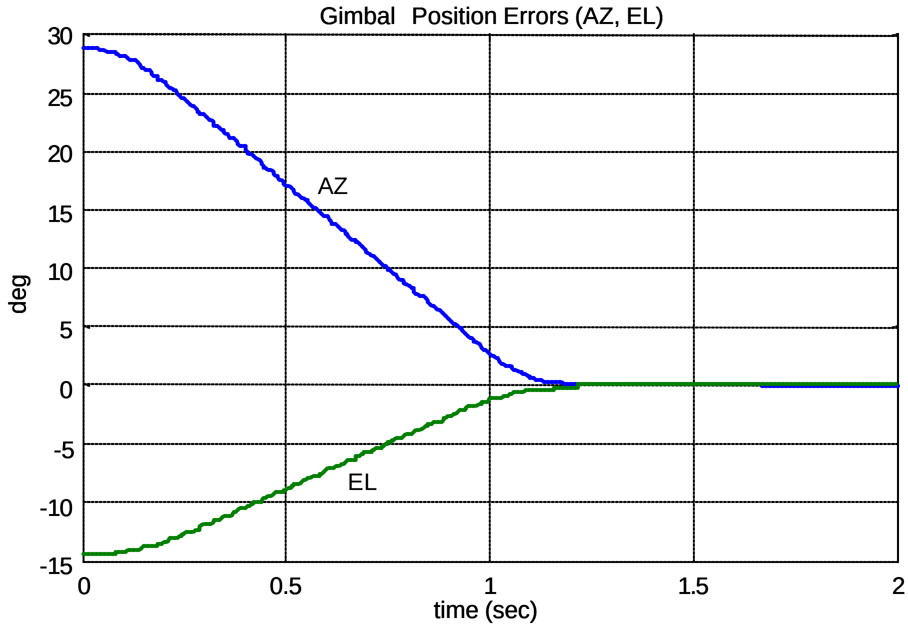

Figure 15: AZ and EL Gimbal Position Errors During Vector Move

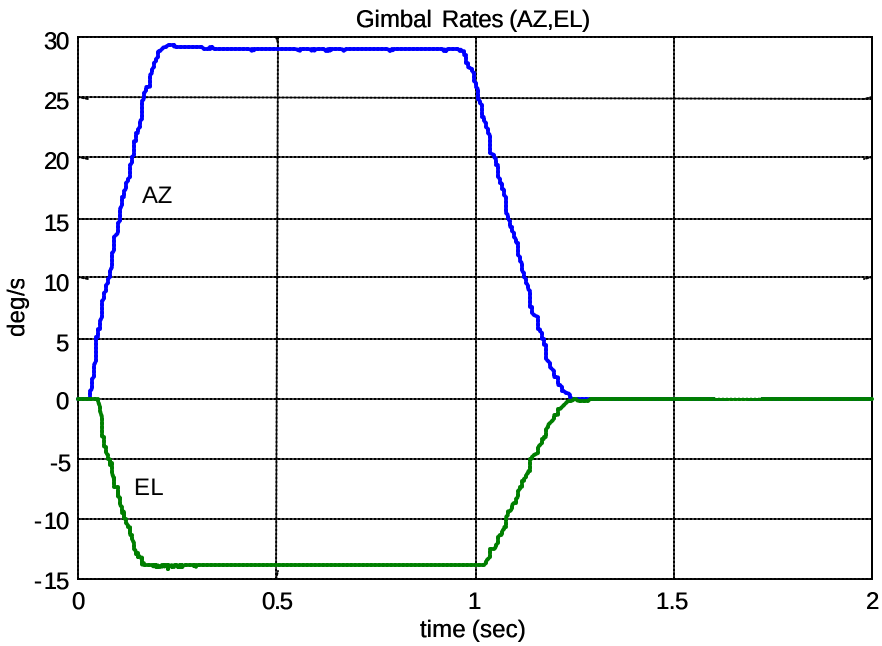

Figure 16: AZ and EL Gimbal Rates During Vector Move

3. STABILIZATION OPTION

3.1. Closed Loop Control and Stabilization

Sagebrush Technology's servo-controlled gimbals are closed loop positioners. This means that feedback is incorporated into the control loops. There is a control loop for the azimuth axis as well as the elevation axis. This control loop for each axis is depicted in Figure 2.

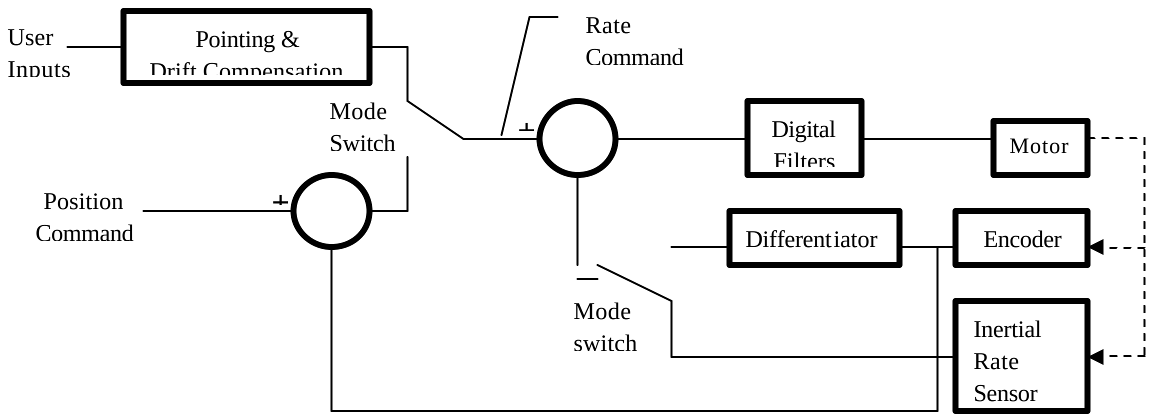

Figure 2. Control Loop Block Diagram

The control loop routine utilizes proportional gain to drive the error signal that is generated between the commanded rate and the measured rate to as close to zero as possible. The control loop also utilizes integral gain to reduce the steady state residual error left from the proportional correction to a near zero state. This is how the closed loop control drives the measured rate to the commanded rate value.

There are two kinds of control loops. One is called the "relative" loop. This loop utilizes a differentiated encoder positional signal to derive velocity. This velocity is measured from the axis mechanical ground on the gimbal. The second type of control loop is called the "stabilized" control loop. This loop utilizes an inertial rate sensor such as a gyroscope to measure the gimbals axis rate of angular velocity against an inertial reference. This type of loop is used to drive out the motion of say a "rocking" boat.

Figure 2. depicts the points in the control loop where sensors can be switched to switch the gimbal from "relative" mode to "stabilized mode".

Closed loop servo controlled gimbals have to be "tuned". This tuning involves the setting of the proportional and integral gains in the control loops as well as providing filters such as "notch" filters so that resonant frequencies of the gimbal and payload are not excited by the controller that is implementing the control loops.

There are three main factors that affect the tuning and stability of the gimbal control loops. These factors include:

- Payload inertial

- Payload Center of Gravity
- Payload stiffness.

There can be degradation in the performance of the gimbal is the payload properties are changed after tuning has been accomplished. The set gains in the control loop may be too high if the new payload has less inertia. This may make the gimbal become unstable.

If the new payload has more inertia, the gains in the control loop may be set to low. This may result in a sluggish response of the gimbal to commands.

3.2. Note of Caution

Inertial rate instruments, such as gyroscopes, are extremely susceptible to damage from mechanical shock. The gimbal should not be placed in an environment that produces mechanical shock levels that approach those that can damage the sensors.

3.3. Stabilized Operation with a Joystick

When Sagebrush Technology provides a stabilized gimbal with a CTI Industrial Mouse(r), the mouse buttons are configured to support specific stabilization functions. The following describes the configuration and function of the “Left”, “Center”,” Right”, mouse buttons:

Left Button – Inertial/Relative Mode

The left button toggles between relative (unstabilized) and inertial (stabilized) modes.

Middle Button – Home

The middle button drives the gimbal toward home while pressed. When released, the gimbal returns to the previous mode.

Right Button – Drift Control

Pressing the right button stores the current joystick command as an offset to subsequent commands. This is used to cancel drift by moving the joystick until the gimbal is stationary, then pressing the right button.

Note: Before the CTI Industrial Mouse® can be used, the gimbal must recognize that the mouse is attached. This can be accomplished by holding the joystick off center in any direction for a brief moment or by depressing any of the buttons at least two times. This action sends a data stream which alerts the gimbal that the CTI Mouse® has been attached and is ready for use, however, the gimbal will not follow commands sent from the CTI Mouse® until an initialization or fast initialization of the gimbal has been completed (Unless otherwise specified the gimbal will be configured to perform a fast initialization upon power up). If an initialization is not performed on power up (based on a factory configuration variation request) the stabilized servo system must be sent the fast initialization command through port “A” from a device capable of using the TASS protocol because the command is not available on the mouse. After the initialization is complete, sending the home command from the mouse (center button) ensures that the gimbal will respond to joystick commands.

3.4. Stabilized Operation from a GUI or Computer

The following TASS commands are available for use with a stabilized gimbal. These commands can be entered from the TASS Command Window of any Sagebrush-supplied GUI, or formatted as described in the Servo Command Set Manual and issued from the serial port of a computer that is communicating with the gimbal:

***mrf,f** = AZ rate, EL rate in rad/sec in ASCII-decimal.

Sets rate commands to the values in radians per second. Automatically sets the gimbal to rate mode (inertial mode for stabilized systems). This command can be used to counteract inertial drift motion of the axes.

HI Set to inertial rate mode (stabilized systems only)

Changes gimbal mode to inertial rate. Same as *mr0,0

***sgrx,1,f = sets inertial rate gain.**

The variable “x” describes the axis; “0” being azimuth or “pan” and “1” being elevation or “tilt: axis. The variable “f” describes the gain level being set.