

Sarnicola Simulation Systems

APPLICATION NOTES

for the

Triad-Series Motion Platforms

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1.0 GENERAL DESCRIPTION

A Triad-Series motion platform consists of a triangular base frame with three hydraulically actuated legs supporting a similar triangular steel moving frame at its three vertices. The extension of the three legs determines the pitch, roll, and heave condition of the moving frame. Each leg consists of two parts hinged at the middle, with a hydraulic cylinder controlling flexure at the knee joint. The bottom of each leg is attached to a vertex of the base frame by a trunnion, and to the corresponding vertex of the moving frame by a ball joint. The trunnion and knee joint configuration constrains each leg to remain in the vertical plane defined by its corresponding vertex and the center of the base frame.

The frames and legs are constructed of steel box beam with welded joints for strength and rigidity. The base trunnions and knee joints are sufficiently massive to provide rigidity against torque due to the inertia of the platform and its load.

The hydraulic cylinders are controlled by high bandwidth servo valves. The cylinders are standard stock models selected to meet the requirements of the application.

The system is powered by a hydraulic pumping unit (HPU) sized to meet the customer's requirements. A separate manual is provided for the HPU.

Leg position is controlled by an electronic servo controller, which is in turn controlled by a standard PC type computer. Leg position is read by a rotary feedback potentiometer mounted at the Rod Clevis of each leg.

There are three types of controllers currently in use. The Sarnicola Dual-Mode Driver (DMAD) Card is a full-length PC card that resides in the host computer and interfaces to it by way of a commercial six-channel DAC card, also housed in the control computer cabinet. This arrangement is now considered obsolete. Users are referred to Rev 1a of this document for information on using the DMAD system. The current standard controller is a stand-alone box that interfaces to the computer via the parallel port (PPIO). SSS also offers a six-channel controller that interfaces via the USB port. Although this controller, the HexUSB, is intended primarily for the Hexad series of motion platforms, it works quite effectively for the Triad series, and is especially useful for computers that do not support the parallel port, or which run NT-based operating systems.

Software for general test and demonstration is provided. In addition, software for playing back entertainment rides is also available. SSS can provide custom software to meet any application need.

2.0 GENERAL TEST SOFTWARE

2.1 Getting Started with TriTest

The program TriTest.exe is a general purpose test and operation program for all Triad-Series motion platforms. The program allows keyboard and mouse control of the platform and provides standard test profiles useful for demonstration and alignment. All functions of the program are indicated on the screen.

To install the program, run the familiar setup.exe program from the distribution media. To make TriTest work with a specific platform, you must update the TriTest.ini file. From within TriTest, press the "e" key on the keyboard. You will see a setup window. Select the platform type and controller type from the two drop-down boxes and click Save. Note that you will have to restart TriTest for the changes to take effect. (Whenever Tri-Test.ini is updated, the previous version is saved as TriTest.bak.)

TriTest will run reliably from Windows95 and Windows98, but it will not work with WindowsNT. (It is untested with Windows2000, WindowsME, and WindowsXP.) Always start TriTest first before starting the platform hydraulic pump. The platform is uncontrolled if the software is not running.

2.2 Using TriTest

Launch TriTest by double-clicking its icon. (Do not start the HPU until TriTest is running and the platform is settled.) The main screen provides a complete description of the state of the platform and controls for operating it manually or running standard test profiles.

Usage should be obvious if you know a few definitions:

Settled means that the platform is lowered all the way down, so that all three legs are collapsed. TriTest always initializes in the settled position, and always settles before quitting.

Homed means that the platform is in its mid position and level. (Pitch, Roll, Heave, and Yaw are all zero.)

Extended means that all three legs are completely extended.

Pitch is the angle of the "nose" from the horizontal. The program displays pitch in degrees up from horizontal.

Roll is the angle of the "wings" from the horizontal. The program displays roll in degrees, with roll to the right (rising left "wing") positive.

Heave is the height of the center of the platform. The zero of heave is at the midpoint of its total heave excursion (the homed position if pitch and roll are also zero). Heave is displayed in inches from the midpoint. Positive heave is DOWN; negative heave is UP (there are technical reasons for this peculiarity).

2.2.1 General Commands

a. State Vector. The system motion state is given in the two frames labeled "Attitude" and "State Vector." You may adjust the state manually by entering state vector values directly or by using the scroll bars on each field.

b. Settle Button. Clicking Settle causes the system to settle, that is to move to its lowest state with all legs fully retracted.

c. Home Button. Clicking Home causes the system to home, that is to move to a level attitude at the midpoint of its heave range.

d. Extend Button. Clicking Extend causes the system to extend, that is to move to its highest state with all legs fully extended.

e. Quit Button. Clicking Quit causes the platform to settle, and then terminates the program. With no data updates to the controller, the controller will continue to command a settled condition.

f. Freeze Button. Clicking Freeze causes the platform to stop moving. The Freeze button becomes the UnFreeze button. In the Freeze state, all controls except the UnFreeze button are disabled.

2.2.2 Profiles

In order to facilitate testing, TriTest provides four oscillatory test profiles, selected using the option buttons in the Profiles frame. The Heave profile, for example, is simply a sinusoidal oscillation in heave. The Quad profile is a combination of a sinusoid in pitch and in roll, with the two axes out of phase by 90 degrees. The Test profile is the Automated Readiness Check described in section 3.3 below.

To start a profile, simply click the Start button in the Profiles frame. To stop it, click Stop. Iteration rate is the frame rate at which the controller is updated in Hz. Form Frequency is the frequency of the profile oscillation in Hz. Amplitude is the amplitude of oscillation in percent of maximum.

When Form Frequency is set to zero, the test profile changes from a sinusoid to a step function of the selected amplitude in the selected axis.

2.2.3 Using the Automated Readiness Check

The Automated Readiness Check feature only operates with the HexUSB controller.

With TriTest running, select the Test option button in the Profiles frame. Click Start. The test will proceed automatically from this point. Click Quit when the test is complete.

The Automated Readiness Check saves its data in the file c:\TriTest\TestLog.txt. This file may be used to analyze system performance. The file is in ASCII format and is laid out as in the following example:

```
Motion System Readiness Check <-----Title
18Feb02  1946  <-----Date and Time

Frame Rate =  30  Hz  <-----Frame Rate
Scale Factor = 124  counts/inch at mid-step  <---Scaling of data
Step starts at frame = 1250  <-----Location of Step Data

1  <-----Frame Number
  2048  2048  2048  <-----Commanded DAC Number (1,2,3)
  2051  2044  2060  <-----Actual DAC Number
2                                     Etc.
```

2.3 Ride Files

A Ride File is a data file containing a frame-by-frame description of platform motion. TriTest does not support ride file playback. For ride playback, SSS provides a complete entertainment ride system called TriRide.

3.0 CONTROL HARDWARE

3.1 Basic Hardware Configuration

Connecting the TriadPPI motion controller is very easy. The controller has two DB-25 connectors, one labeled "Platform" and one labeled "Computer." Using a straight-through wired cable with DB-25P connectors on both ends, connect the computer's Printer Port to the connector labeled "Platform" on the controller. This cable should not be more than five feet in length. Using a straight-through wired cable with a DB-25P on one end and a DB-25S on the other, connect the platform to the connector labeled "Platform" on the controller. This cable may be up to 100 feet long.

The DE-9 connector on the controller is for digital I/O in special applications.

The controller plugs in to standard 115V 50-60 Hz power. The power input wiring on the circuit board may be modified easily to accommodate 220 volt power.

3.2 Tuning

This procedure applies specifically to the TriadPPI controller. Tuning of the HexUSB controller is very similar. For information about tuning of the DMAD controller, please refer to Version 1a of this document.

The controller circuit board is laid out with the three servo controllers on the right side of the board as seen from the front. At the extreme right of each channel are three trimpots used for tuning the legs. The pots are labeled Zn, Dn, and Gn, where n is the leg number, and Z is for Zero, D is for Damping and G is for Gain. These are 25-turn pots; clockwise increases the value of the controlled parameter. Use the following procedure to tune the system. The legs are numbered clockwise as seen from above, starting with the front leg.

a. If starting from a completely unconfigured board, preset the pots to the following values (from full CCW):

Zero: 10 turns
Damping: 4 turns
Gain: 20 turns

b. With the pots preset, start TriTest and energize the HPU.

c. With TriTest commanding settle, adjust the Zero pots so that each leg is just off the stops in the settled position. This adjustment requires some care because the cylinders are operating in the cushion range and will be somewhat sluggish. A good strategy is to move the cylinder off the stop and then incrementally move the leg towards fully retracted. A good final setting leaves the cylinder about 1/8 inch extended.

d. The gain setting is about right at 20 turns. Increasing gain may be useful if particularly rapid response is necessary.

e. Home the platform with TriTest, and observe any performance differences from leg to leg. The best performance will be had with the damping adjusted just enough for zero overshoot, although some applications may require more damping to limit performance. In the Profiles frame on TriTest, set Amplitude at 30 percent, and Form Frequency at "Step" (zero). Click Start, and observe the behavior of the legs. Adjust the damping pot for each leg to get identical behavior and the desired performance. Clockwise increases damping.

4.0 SOFTWARE CONTROL

Software control of the Triad platform requires a transformation from an expression of the desired platform attitude in some convenient coordinate system to the leg fold angles as measured by the position feedback pots. Given the leg fold angles, the computer then commands a voltage analog for pot position on each leg, and the Controller controls the valves to drive each leg to its commanded extension.

4.1 Coordinate Systems

The standard coordinate system used nearly universally in vehicle simulation is a right-handed cartesian system with the x-axis in a cardinal direction, the y-axis to the right, and the z-axis down. For the vehicle coordinate system, the x-axis is forward in the vehicle, the y-axis is out the right side, and the z-axis is down. Mnemonically, this coordinate system is often called the "nose-wing-down" or "NWD" system. Similarly, the Earth Frame is typically x-axis north, y-axis east, and z-axis down. The mnemonic is "north-east-down" or "NED." (The fact that the z-axis is down can take some getting used to, but it is necessary to keep the system right handed while placing the x-axis on the axis of symmetry.)

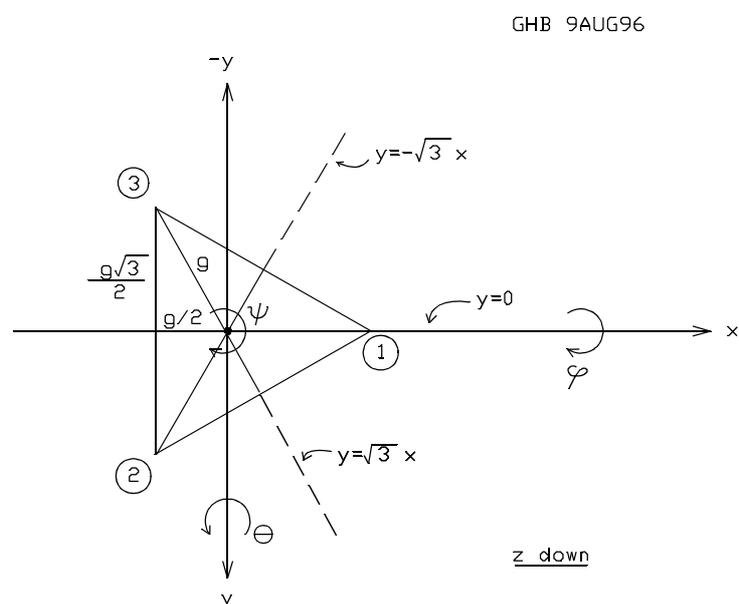


Figure 4-1. Plan view of platform layout showing coordinate systems and frame dimensions.

Conforming to this standard, the Fixed Frame for the Sarnicola Motion Platform has its origin at the centroid of the triangle formed by the three of lower joints. The x-y plane lies in the plane of this lower triangle. The x-axis projects out the front of the platform, the y-axis projects out the right side, and the z-axis points down. The x-y plane of the Moving Frame lies in the plane of the upper joints of the platform, with its origin directly above the origin of the Fixed Frame when the platform is settled. Similarly, its x-axis projects forward, its y-axis projects out the right side, and its z-axis points down.

Figure 4-1 shows a schematic plan view of the platform, indicating the arrangements of the coordinate systems and the naming of the various joints. In this view, the three Fixed Frame (base) vertices (called F1, F2, and F3) are exactly covered by the three moving vertices (called M1, M2,

and M3). The vertices are labeled simply 1, 2, and 3. Note that the M1 vertex is on the positive x-axis of the Moving Frame, and the F1 vertex is on the positive x-axis of the Fixed Frame. Each of the three legs are identified with the number of the associated moving and fixed vertices. Since the platform is based on an equilateral triangle, only a single dimension is required to specify its size. That value is the vertex radius, given by g . The coordinates of the three base vertices (in the Fixed Frame) are easily computed knowing the value of g .

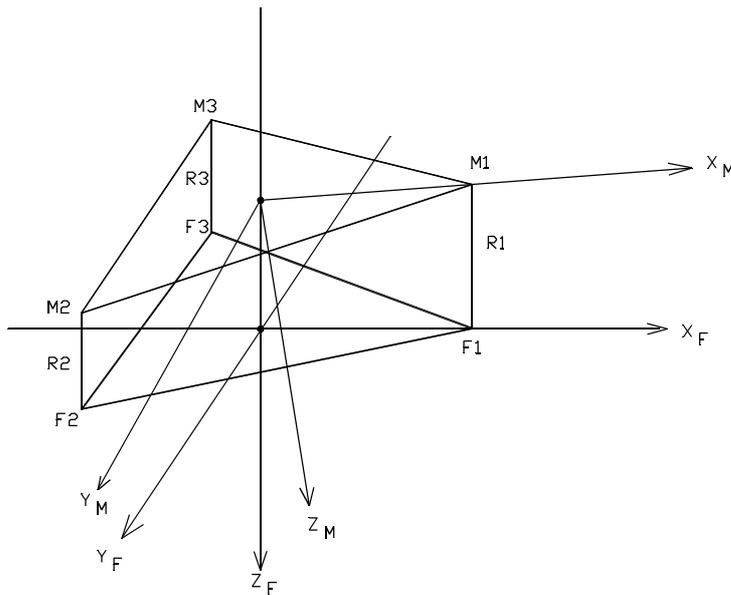


Figure 4-2. Geometrical relationship between the Moving and Fixed Frames, showing leg extensions.

settled onto the lower hard stops of all three legs, that is with all three legs retracted. The Extended position is the position in which the platform is as high as it will go against all three hard stops, that is, with all three legs completely extended. In the Home position, the platform is level and midway between Settled and Extended. In the Home position, the legs are said to be at mid-extension, but it is important to realize that mid-extension is not halfway between retracted and extended. Mid-extension on all six legs divides the full Heave (z) excursion in half. The full Heave excursion is called DZ . It is convenient to express the attitude of the platform in a fixed coordinate system with its origin at the origin of the Moving Frame in the Home position. This frame is called the Command Frame. For a commanded value of Heave of, say, +3.7 inches, the platform would be 3.7 inches below Home position. The commanded value of Heave for the Settled position is therefore $+DZ/2$.

Figure 4-2 shows an isometric view of the coordinate system, illustrating the relationship of the moving and fixed frames. The leg extensions $R1$, $R2$, and $R3$ are simply the distances between the trunnions (the fixed vertices) on the base frame and the ball joints (the moving vertices) on the moving frame. The valve control channels for each leg are numbered 1 through 3 starting with Leg 1 on the x-axis and proceeding clockwise around the platform.

Figure 4-3 shows a schematic elevation with the Settled, Home, and Extended platform positions illustrated. The Settled position is the position in which the platform is

The Fixed-Frame z-coordinate of the origin of the Command Frame is called Z_0 when the platform is homed ($z=0$); and Z_S when the platform is settled ($z=+DZ/2$). The values of these critical geometrical constants are tabulated in Table 4-1.

The values of Z_S , Z_0 , and DZ are determined by the geometric constants (the coordinates of the joints) and by the retracted extension of the legs R_{min} , and by their fully extended length, R_{max} .

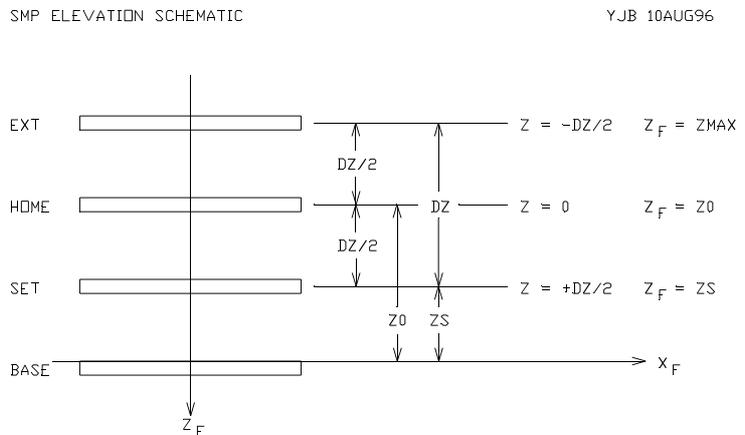


Figure 4-3. Schematic elevation showing platform cardinal positions.

4.2 Expressing the Attitude

The attitude of the platform may be expressed using conventional Euler Angles and Cartesian position coordinates. Given the commanded Roll, Pitch, and Heave of the platform, it is straightforward to compute the rotation matrix and translation vector for the platform, and from those, the three leg extensions. Figure 4-2 shows how the two triangular frames of the platform relate to the two coordinate systems, and how the attitude of the platform is completely determined by the three leg extensions. The control software takes the commanded Roll, Pitch, and Heave, and uses them to compute the rotation matrix (L_{ij}) and the translation vector $(0, 0, Hev)$. It then uses these to compute the positions of each moving vertex in the Fixed Frame coordinate system. The leg extensions are then the distances between the fixed vertices and their corresponding moving vertices.

Since yaw, surge, and sway are not involved in computing leg extensions, the rotation matrix and translation vector are quite simple. Note that the rotation produced by the Yaw Table, if installed, is rotation about the moving z-axis, rather than the fixed z-axis, in the conventional order of rotations. It is probably best to consider Yaw separately from the other rotations.

4.3 Leg Geometry

Leg extensions are computed from a detailed analysis of the geometry of the folded leg. The geometric constants needed for these computations are included in the initialization file `TriTest.ini`.

Once the leg extensions (R1, R2, R3) have been computed, the software finds the fold angles (Alpha1, Alpha2, Alpha3) for the three legs. Figure 4-4 shows the geometry of a single leg, illustrating the relationships among the fixed distances between components (A-F), the leg extension (R), and the pot angle (α). The position pot is located at the Rod Clevis where it pivots on the upper leg. Figure 4-5 shows how the leg articulates.

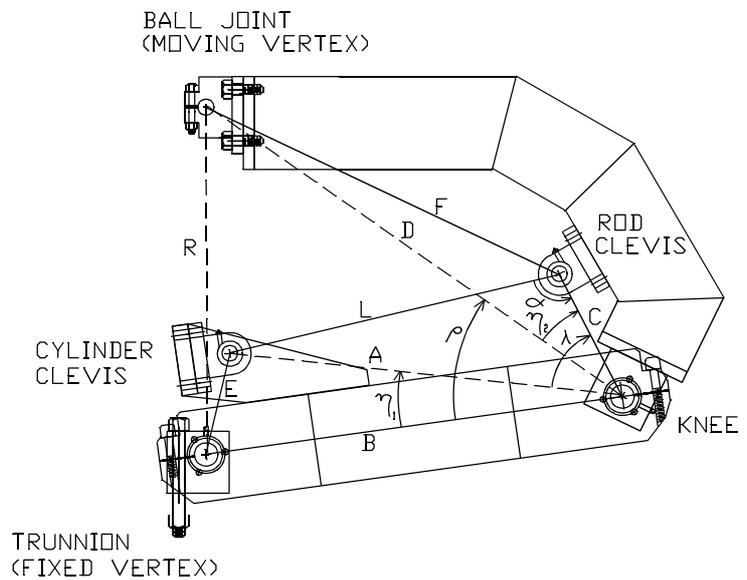


Figure 4-4. Leg geometry for a single leg.

Control of the Yaw motor is more straightforward since the yaw position potentiometer reads yaw angle directly. The yaw pot is active over ± 160 degrees of rotation, but the actual yaw excursion should be limited to ± 140 degrees of rotation. Alpha for Yaw is simply the commanded value of Yaw.

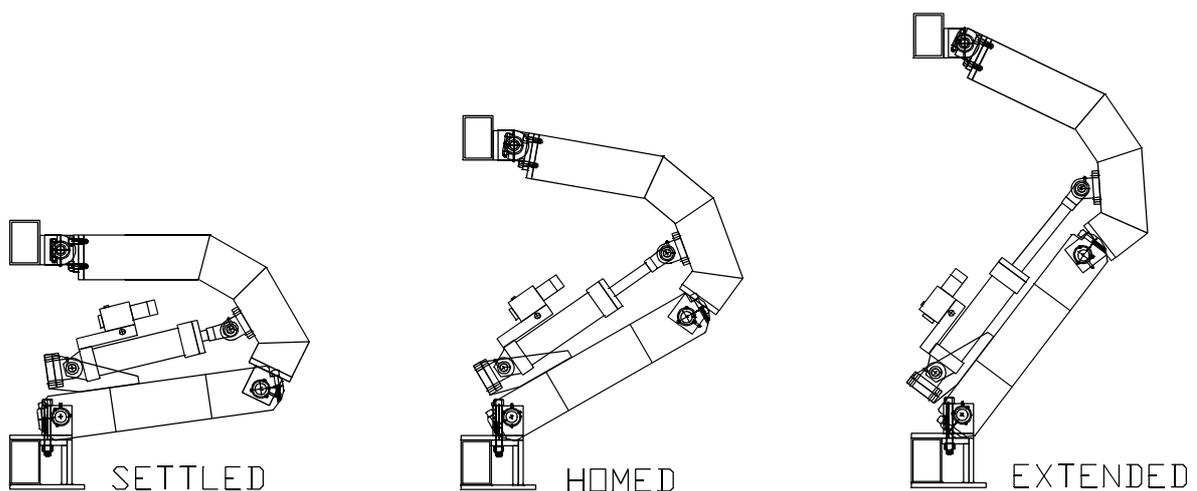


Figure 4-5. Articulation of the SMP leg.

4.4 DAC Control

Once the pot angles (Alpha1, Alpha2, Alpha3, Alpha4) have been computed, then all that remains is to compute an appropriate DAC number for each leg and transmit it to the DAC card. This computation depends upon the details of the input circuits of the controller in use and the specific wiring of the leg feedback pots.