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International Space Station Remote Sensing Pointing Analysis

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Abstract—This paper¹² analyzes the geometric and disturbance aspects of utilizing the International Space Station for remote sensing of earth targets. The proposed instrument (in prototype development) is SHORE (Station High-Performance Ocean Research Experiment), a multi-band optical spectrometer with 15 m pixel resolution. The analysis investigates the contribution of the error effects to the quality of data collected by the instrument. This analysis supported the preliminary studies to determine feasibility of utilizing the International Space Station as an observing platform for a SHORE type of instrument. Rigorous analyses will be performed if a SHORE flight program is initiated.

The analysis begins with the discussion of the coordinate systems involved and then conversion from the target coordinate system to the instrument coordinate system. Next the geometry of remote observations from the Space Station is investigated including the effects of the instrument location in Space Station and the effects of the line of sight to the target. The disturbance and error environment on Space Station is discussed covering factors contributing to drift and jitter, accuracy of pointing data and target and instrument accuracies.

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1. INTRODUCTION

This paper provides an analysis of the factors affecting a remote sensing optical spectrometer flying on the International Space Station (ISS). The instrument is the

Station High-Performance Ocean Research Experiment (SHORE). The analysis considers the geometric and disturbance factors and errors affecting the quality of image capture using the SHORE instrument. SHORE targets consist of coral reefs, atolls, tidal areas and coastal interfaces. These targets present a difficult subject to image due to the high reflectivity of the land and the low reflectivity of the water. SHORE's high dynamic range provides a high sensitivity capability well suited to targets of this type.

SHORE Overview

The SHORE instrument is planned to be a multi-band optical spectrometer covering the 390 through 1000 nm wavelengths in multiple (potentially 16 to 25) bands. SHORE would provide high dynamic range due to the ability to assign multiple detector pixels to each filter band and to repeatedly image the same points on the target. The SHORE instrument would be mounted within the Window Observational Research Facility (WORF) that would be located within the U. S. Laboratory module in ISS.

The SHORE imager would be a CCD type detector. The CCD window will be covered with an interference filter array. The filter array consists of multiple optical bands covering rows of detector pixels in length and varying pixels wide. Widths of spectral bands are selected based on the characteristics of the signal at the wavelength involved.

The efforts to date have focused on a SHORE prototype instrument. The goals are to characterize and quantify the performance of this approach. The data collected will provide the necessary information to decide if pursuing a flight instrument is reasonable and what the specific technical requirements and science goals would be practical. The SHORE prototype is based on a 1920 x 1080 CCD array with 12.5 micro-meter pixels, a frame rate of up to at least 30 frames per second and 12 bit resolution per pixel. This specification drives many of the quantities utilized in this paper.

ISS Remote Sensing Overview

ISS provides unique capabilities as a remote sensing platform. The orbital period of approximately 90 minutes provides frequent passes over 58% of the earth's surface.

¹ —————
¹ "U.S. Government work not protected by U.S. copyright."
² IEEEAC paper #1054, Version 2, Updated Dec. 11, 2006

The orbital inclination of 51.7 degrees allows target access up to 52.7 degrees in latitude. Based on the targets identified by the science team, ISS orbits pass over targets multiple times within reasonable periods to allow effective revisits of identified sites.

ISS also provides an orbital observing location and environment that allows development and testing of instruments without the risk and cost burden of free flying platforms. Instruments can be designed and operated more easily in the pressurized and temperature controlled environment of ISS alleviating the problems associated with direct exposure to space. Additionally, due to the repetitive access to ISS, instruments can be returned to earth for modification, new instruments can be carried up to test new technologies and techniques, on orbit adjustments and modification can be performed by the crew and impromptu/adhoc images can be taken. The instrument can be operated remotely with no crew involvement or crew attendance if necessary.

For a SHORE type instrument the advantages of flying on ISS outweigh the disadvantages. However, there are disadvantages to consider: disturbance rich environment relative to free flier platforms, physical limits on size, weight, power, cooling; resource contention, additional requirements for flying in a man rated system. However, for multiple classes of instruments, ISS offers significant advantages.

Analysis Approach

This analysis considers 2 aspects:

- (1) Target conversion to SHORE pointing knowledge.
- (2) Pointing budget margins.

The coordinate conversions are addressed in sections 3 and 4 including the transformation steps to perform the conversions. The vector approach used in the analysis will be considered in addition to other approaches if a flight development program is initiated.

The pointing budget is covered in sections 5, 6 and 7 and discuss the geometric, ISS pointing knowledge accuracies and disturbance environment. The ISS window, proposed instrument characteristics and the disturbance environment are considered. The pointing budget is organized as shown in figure 1.

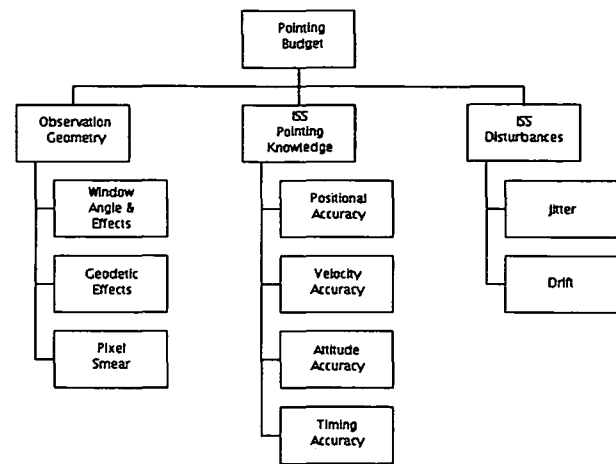


Figure 1 – Pointing Budget Elements.

This analysis provides a preliminary assessment of the pointing budget. A full and complete analysis will be performed in a flight development program. Total accumulative effects and statistical analyses have not been performed.

Definitions

The following are the key definitions [1].

- Absolute pointing accuracy - Total angle difference between actual pointing direction and the desired pointing direction.
- Relative pointing accuracy - Variation of total angle between the actual pointing direction and the desired pointing direction over a time interval required to acquire an image.
- Jitter - Image motion on the time scale of a single exposure.
- Drift - Average motion during time to capture a complete image data set.

Acronyms

- BAD – Broadcast Ancillary Data
- CMG – Control Moment Gyroscope
- FOR – Field Of Regard
- FOV – Field Of View
- GN&C – Guidance, Navigation & Control
- ISPR – International Standard Payload Rack
- ISS – International Space Station
- LOS – Line Of Sight

- WORF – Window Observational Research Facility

2. SHORE REQUIREMENTS

The SHORE project science goals set the instrument pixel resolution, jitter, drift, pointing accuracy and the absolute real time pointing knowledge requirements. These requirements drive a Field Of View (FOV) of 2.5 degrees, pixel smear and image size of 16 km square. The SHORE specifications are described below.

- A SHORE pixel size of 15m was selected to provide the best resolution trade off of science objectives against exposure time, pointing errors and system costs.

- The FOV is based on the pixel size and the number of pixels cross track and along track. A 15 m pixel size determines the SHORE FOV to be 2.5 degrees.

- SHORE requires less than 1/4 of FOV (4 km) absolute pointing accuracy equating to 0.625 degrees. Pointing accuracy will be affected by errors in: GN&C measurement accuracy, time accuracy, disturbances, geometric distortions. Target size is a factor to consider in this specification. Smaller targets will easily fit within the FOV of SHORE while large targets may have difficulty as they approach the FOV limits.

- Jitter and drift are the two values used to quantify the effects of physical disturbances of the Space Station.

- Jitter is defined as image motion on the time scale of a single exposure (33.33ms = 30 Hz). The SHORE specification calls for less than 1/2 of a pixel variation due to jitter. SHORE pixels are 15m therefore the variation must be < 7.5 m, equating to a jitter of < 20 micro-radians.

- Drift is defined as average motion of the Line of Sight (LOS) during time to capture a complete image data set (90 s). The SHORE specification calls for less than 1/4 of a pixel (3.75 m) drift over the imaging period, equating to a drift of < 10 micro-radians.

- **SHORE timing accuracy** is based on the minimum smear a pixel will experience during exposure due to the relative velocity between the instrument FOV and the target. Average satellite sub-point speed is 7.25

km/s, the SHORE requirement is for less than ¼ FOV variation. This translates to a timing accuracy of < 0.55 seconds.

3. COORDINATE SYSTEMS

This section describes the coordinate systems used from the target all the way through to the SHORE instrument. The Space Station utilizes several coordinate systems to support multiple structural and element relationships.

The first coordinate system provides the target location specified in longitude and latitude. Each sequential coordinate system is described in the order from target to SHORE detector. The target, Space Station inertial, Space Station orbital, Space Station body-fixed, U.S. laboratory and International Standard Payload Rack (ISPR) coordinate systems are from Space Station documentation [2].

Target Coordinate System

The target coordinate system provides geodetic longitude and latitude location data based on the ellipsoidal model of the earth.

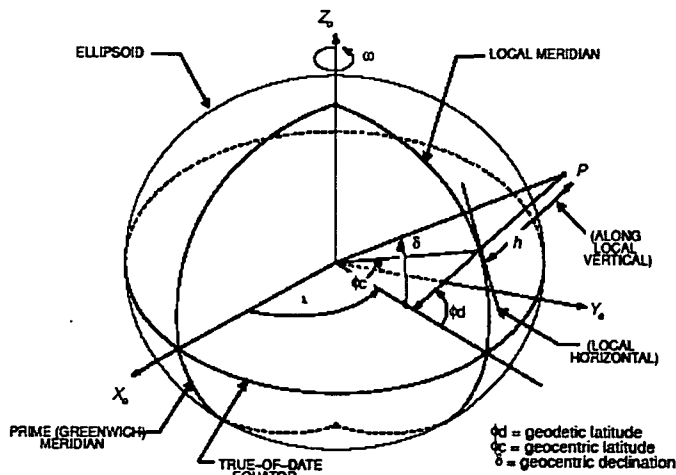


Figure 2 – Target Coordinate System.

The ellipsoidal model accounts for distortions due to the non-spherical earth shape. Longitude is measured from the prime (Greenwich) meridian to target meridian. Latitude is measured from the plane of the Earth's true equator to the target latitude.

Space Station Inertial Coordinate System

The Space Station inertial coordinate system provides inertial coordinates of the ISS center of mass based on the J2000 celestial coordinate system (earth center of gravity and Aries mean of 2000).

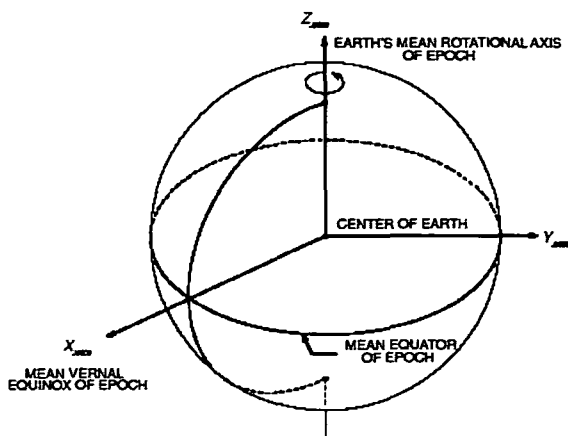


Figure 3 – Space Station Inertial Coordinate System.

The coordinate system is earth centered, inertial and right handed. The X axis points to mean vernal equinox of epoch (2000 January 1). The Z axis is directed along earth axis of rotation. The Y axis completes the right handed system with the X-Y plane located at Earth's mean equator of epoch.

Local Orbital Coordinate System

The Space Station local orbital coordinate system provides reference coordinates in the local orbital vertical and horizontal directions.

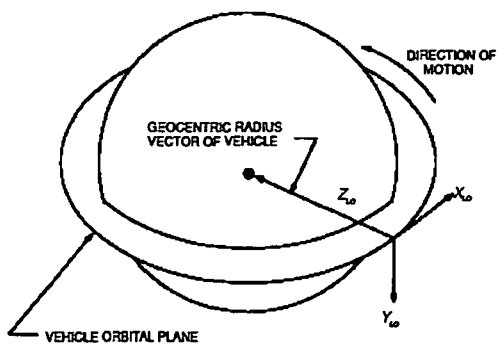


Figure 4 – Local Orbital Coordinate System.

The origin is located at the Space Station center of mass, the X-Z plane is in the instantaneous orbital plane, the Z axis is located along the radius to the center of the earth, the Y axis is normal to the orbital plane, and the X axis completes the right handed orthogonal Cartesian system.

Space Station Body-Fixed Coordinate System

The Space Station body-fixed coordinate system provides reference coordinates based on the axes defined for the entire Space Station structure.

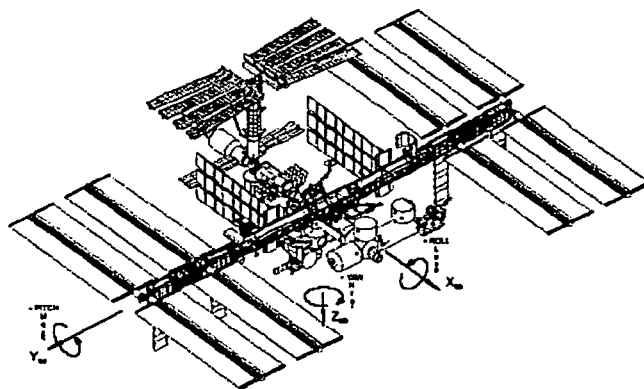


Figure 5 – Space Station Body-Fixed Coordinate System.

The origin is located at the Space Station center of mass. The X axis is parallel with the laboratory module center line. The Y axis is parallel with the starboard truss axis. The Z axis completes the orthogonal system and is typically pointed in the NADIR direction. Pitch, roll and yaw angles are defined in relation to the local orbital coordinate system.

U.S. Laboratory Module Coordinate System

The U.S. laboratory coordinate system provides reference coordinates based on the axes defined for the pressurized module containing WOLF and SHORE.

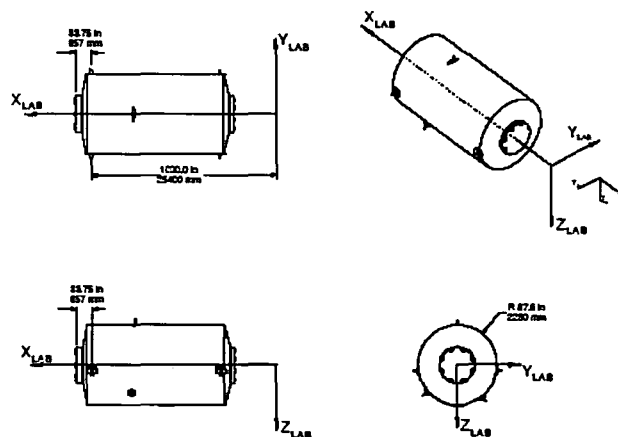
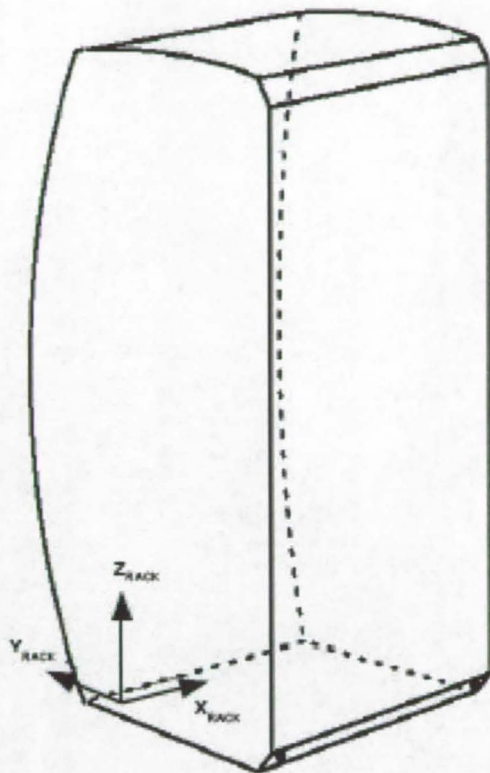


Figure 6 – U.S. Laboratory Module Coordinate System.

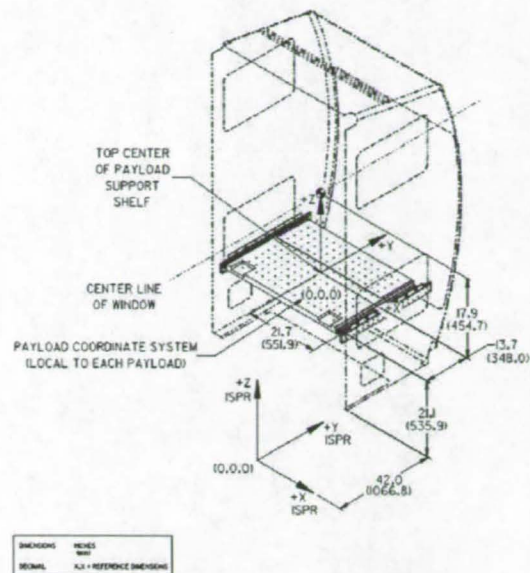
The origin is located 1000 inches forward of the aft trunnion center line. The X axis is located along the geometric center line of the laboratory module. The Z axis is parallel to the line perpendicular with the X axis and through the center line of the keel pin. The Y axis completes the right handed system.

The ISPR body-fixed rack coordinate system provides reference coordinates based on the axes defined for the racks mounted within the laboratory module.



The origin is located at the interface of the centerline bushing attachment at the left front side of the rack. The X axis is in line with the center line of the attachment bushing. The Y axis is parallel with the plane of the rack floor. The Z axis completes the right handed system.

The WORF coordinate system provides reference coordinates for the WORF mounted experiments and equipment [3].



The origin is located at the center of the payload support shelf. The X axis is parallel to the support shelf center line located along the left to right center of the rack. The Y axis is parallel to the center line from the front to rear of the rack. The Z axis completes the right hand system.

The SHORE coordinate system provides coordinates based on the axes defined for the instrument.

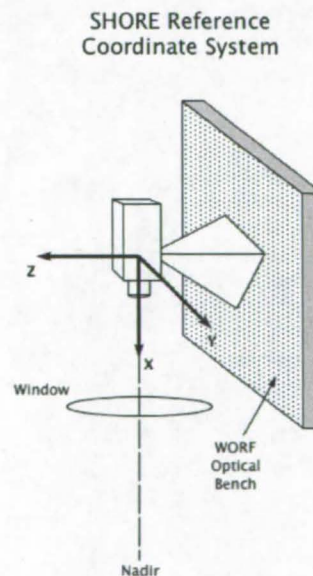


Figure 9 – SHORE Coordinate System.

The origin is located at the center of rotation for the instrument elevation (cross track pointing) axis and the azimuth (along track pointing for nodding) axis. The X axis is the LOS, the Y axis is the elevation axis, the Z axis is the azimuth axis.

4. COORDINATE TRANSFORMATION

This section describes the transformations to translate the target geodetic latitude and longitude to SHORE azimuth and elevation. The discussion describes the approach and steps necessary to convert the target coordinates. Figure 10 below depicts the geometry and angles involved in viewing a target.

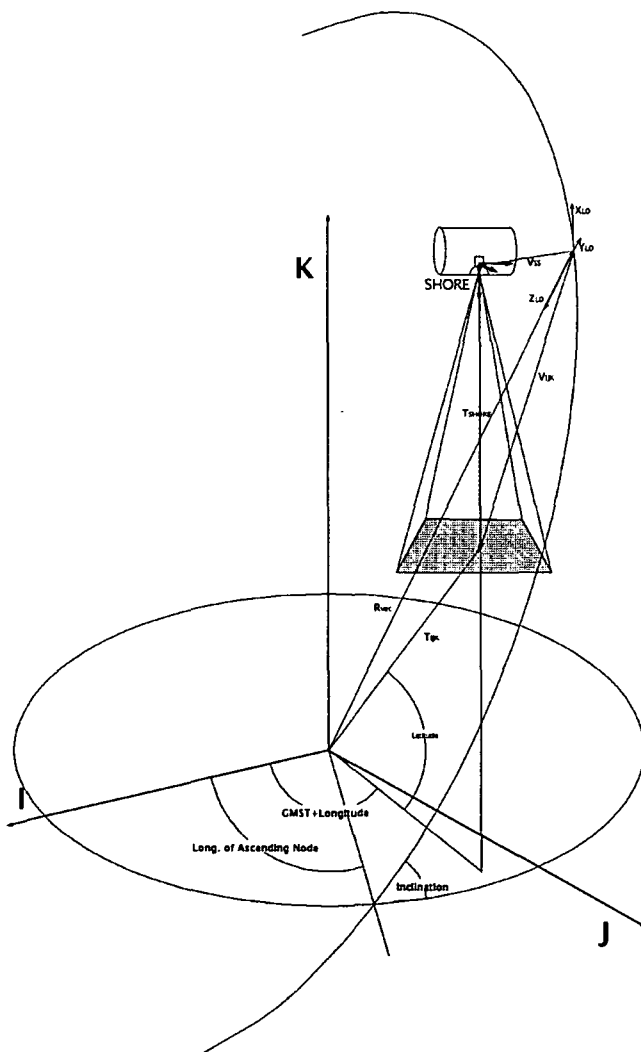


Figure 10 – Geometry Angles.

Transformation Approach

This approach uses vectors and transformation matrices in a 6-step process. Figure 10 provides the vectors involved in the transformation process.

- (1) The target latitude and longitude in addition to the Greenwich Mean Sidereal Time are used to create a vector T_{IJK} from the center of the earth to the center of the target in the IJK earth centered inertial coordinate system.
- (2) The ISS position vector R_{VEC} is known (provided as IJK components in a GN&C measurement). Using vector calculations, the vector V_{IJK} is obtained. V_{IJK} points from the center of the target to the center of mass of ISS (end point of R_{VEC}).
- (3) The first coordinate transformation uses the inclination, longitude of the ascending node, argument of perigee and the true anomaly (calculated from time, R_{VEC} and V_{VEC} or potentially provided in a GN&C measurement) resulting in V_{IJK} expressed in terms of the ISS local orbital coordinate system.
- (4) The second coordinate transformation incorporates ISS attitude (roll, pitch, yaw; provided in GN&C measurements) to convert V_{IJK} from the ISS local orbital coordinate system to the body-fixed coordinate system (V_{LO}).
- (5) V_{SS} is a fixed vector in the ISS body-fixed coordinate system from the ISS center of gravity to the center of rotation of SHORE. A vector calculation is again performed with vector V_{LO} and V_{SS} creating the $T_{SHORELO}$ vector pointing from the SHORE center of rotation in the body-fixed coordinate system to the center of the target. It is coincident with the desired SHORE LOS.
- (6) The final coordinate conversion is performed to express $T_{SHORELO}$ in the SHORE (azimuth and elevation) coordinate system (T_{SHORE}).

This approach provides the LOS coordinates for SHORE to point at the target center. It uses simple vector operations in addition to typical Euler angle transformations. If a SHORE flight development program is started, this approach will be considered in addition to others. The selected approach will undergo rigorous analysis to fully determine its characteristics.

5. OBSERVATION GEOMETRY

The pointing budget elements discussed in this section are shown in the figure 11 below.

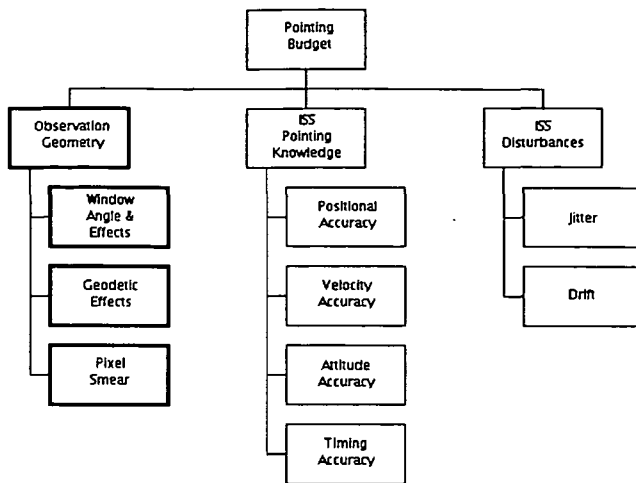


Figure 11 – Pointing Budget Elements.

The analysis of SHORE observations from Space Station that consider the unique observational geometry include: window angles and effects, geodetic effects, imaging angle effects and pixel smear. Figure 12, below shows the overall observation geometry.

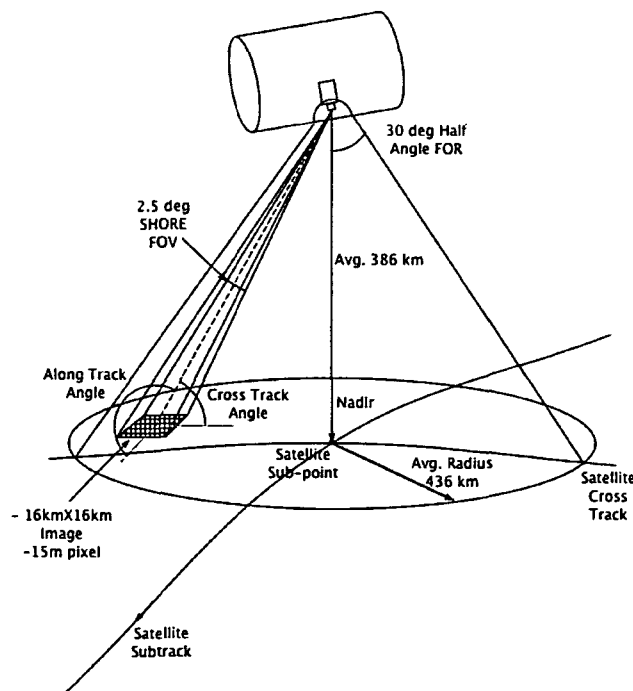


Figure 12 – Geometry Angles.

This analysis uses a Space Station mean altitude of 386 km [4], an inclination of 51.7 degrees and an orbital period of approximately 90 minutes. This provides SHORE image access to 58% of the earth's surface. The inclination and window Field Of Regard (FOR) allows SHORE to image to a maximum latitude of 52.7 degrees north and south. Based

in a previous study [5], targets [6] are available for imaging as frequently as 3 per orbit.

The WORF working group and the SHORE science team determined that the window in Space Station provides a FOR of a 30 degree half angle. SHORE operates within the FOR with a 2.5 degree FOV. SHORE will require an azimuth/elevation pointing capability. Pointing system requirements and specifications will be addressed in the flight instrument development program. The pointing system allows SHORE to acquire targets within the window FOR and to slew the camera to provide the required relative target motion to capture the image and compensate for effects of the ISS orbital velocity.

Window Angles and Effects

At a Space Station average altitude of 386 km the window FOR provides targets within a radius of 436 km from the instantaneous satellite sub-track point. The SHORE azimuth (along track) and elevation (cross track) pointing capabilities allow imaging of targets within this 436 km window FOR.

The Space Station window is located in the US Laboratory Module, facing in the nadir direction. The window is 20 inches in diameter, composed of 3 panes combining to a total thickness of 2.9 inches. The window optical characteristics are described by figures 13 and 14 [7]. SHORE operates in the visible spectrum from 390 nm to 1000 nm. From the window optical characteristics for transmittance in figure 13 (the position numbers on the x axis represent spatially distributed locations in the window), it can be seen that the SHORE spectrum is largely passed by the window in a transmittance range of 0.93 to 0.98 for the wavelengths between 442 nm and 868 nm. Below 442 nm at 412 nm the transmittance drops to approximately 0.75. SHORE calibration and characterization will compensate for this reduction in transmittance values. Additional window data shows transmittance above approximately 0.85 out to 1000 nm.

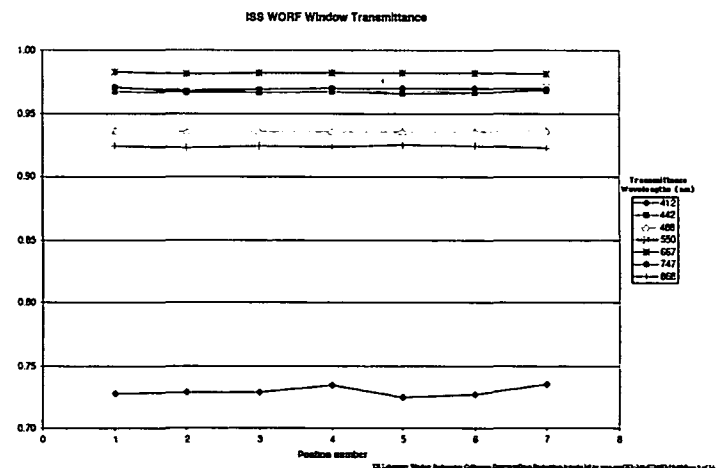


Figure 13 – Space Station Window Transmittance.

Figure 14 shows window transmittance as a function of viewing angle. SHORE will look through the window at angles up to 30 degrees. The SHORE wavelengths of interest between 442 and 868 nm pass through the window at 0.87 to 0.98 transmittances for the full 30 degree viewing angle range. Below 442 nm at 413 nm the transmittance varies from 0.72 to 0.87. Again, SHORE calibrations and characterization will allow correction of the angular effects of the window transmittance.

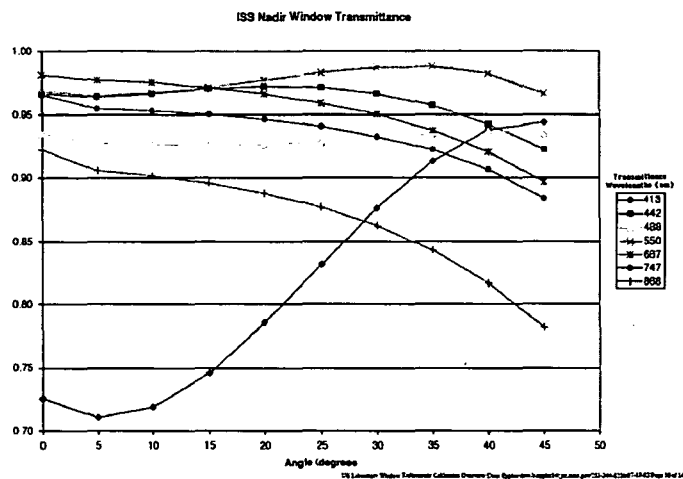


Figure 14 – Space Station Window Angle of Incidence Transmittance.

SHORE placement in WOLF would locate the lens opening as close as possible to the window. Additionally, an optimized pointing system would provide a center of rotation at the opening of the lens, minimizing the distance the center of the lens moves from the center of the window. This pointing approach maximizes the quality of SHORE viewing through the window. However, the approach may increase the effect of disturbances due to the SHORE center of mass and center of rotation not being co-located.

Geodetic Effects

Geodetic effects can distort images due to the non-planar image field.

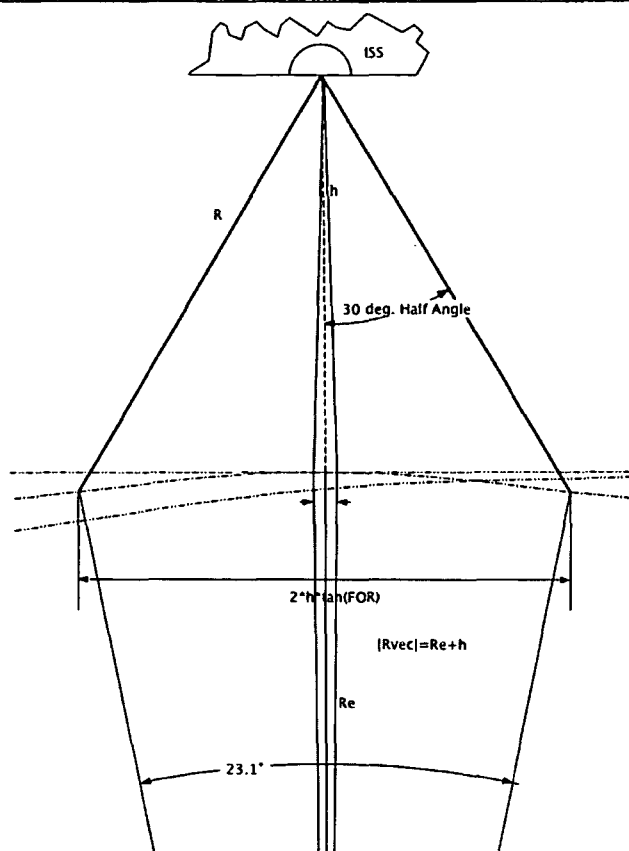


Figure 15 – Geodetic Effects.

The geometry of observations from ISS distorts the target image. The geometric effects cause pixel dimensional variations due to cross track and along track angles. Figures 15 and 16 illustrate the geodetic effects and dimensional variation due to off nadir pointing angles.

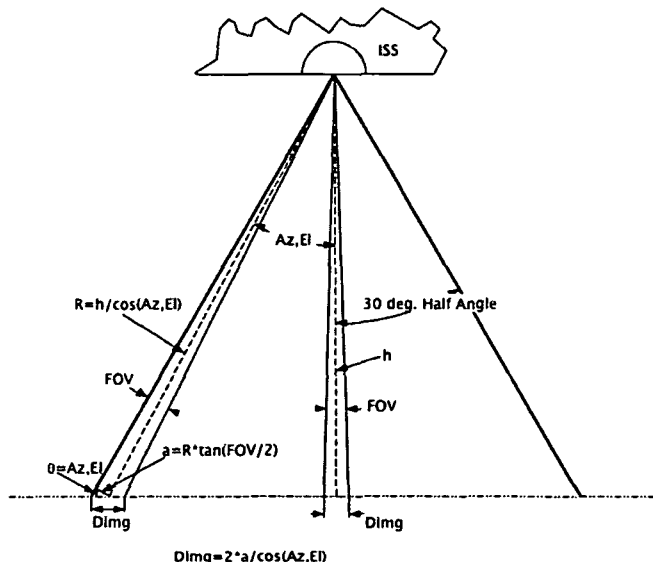


Figure 16 – Image Angle Effects.

The distortion is greatest at the edges of the window FOR (full 30 degree half angle). The pixels become 12.5% longer in the radial direction outward from the satellite sub-point. For 15 m pixels used by SHORE this adds 1.9 m.

The SHORE requirement of absolute pointing accuracy calls for an error effect of less than $\frac{1}{4}$ the FOV. This equates to 4 km. The pixel distortion error is well within the SHORE requirement.

Pixel Smear

Pixel smear occurs due to the relative motion of the target during the individual frame integration times. For shorter integration times, smear is reduced while longer integration times increase smear. The SHORE specification calls for less than a full pixel of smear. This equates to one pixel (15 m) moving one full pixel distance (another 15 m) during the frame integration time. The smear is compensated for during data processing where the image is re-sampled to include all photons received from the ground element 15 m wide by 15 m+smear long into one 15 m x 15 m element. Smearing reduces the image resolution in the along track direction.

The SHORE integration time is 1/30 of a second (33.33 ms). During this time the instantaneous line of sight of SHORE is required to move less than 15 m. This results in a line of sight velocity of 454.5 m/s. The pointing system to be used will provide adequate accuracy and resolution and the data processing will be adequate to meet the specification.

Conclusion

The observation geometry factors do not violate the SHORE requirements. The window angles and effects, geocentric effects and pixel smear aspects meet the SHORE requirements with margin. The accumulative effects of the errors have not been assessed. A more detailed analysis would characterize the over all effect of the errors.

6. ISS POINTING KNOWLEDGE

The pointing budget elements discussed in this section are shown in the figure 17 below.

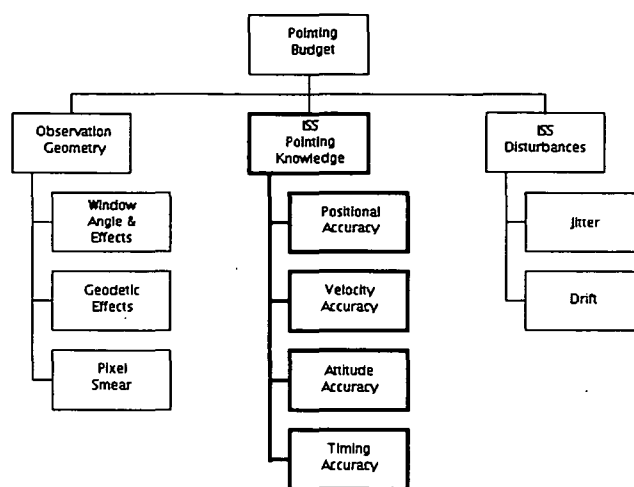


Figure 17 – Pointing Budget Factors.

This section analyzes the ISS position, velocity, attitude and time measurements that SHORE would use for pointing and image acquisition. SHORE pointing requirements are the current resolutions and accuracies set for the prototype instrument. The values may change as instrument development progresses. The accuracy and resolution of these measurements are considered based on the SHORE requirements.

Accuracy of ISS GN&C Data

ISS provides on board measurements accessible to instruments that indicate the orbital location, velocity, attitude and time. These measurements will be used by SHORE to point the instrument at targets and acquire images. The accuracy of the ISS measurements effect the quality of SHORE pointing and image acquisition. The measurements used are: position and velocity vectors in IJK components based on the geocentric inertial J2000 reference system; roll, pitch and yaw ISS attitude angles; and GPS time. These measurements are distributed using Broadcast Ancillary Data (BAD) packets. The BAD packets are cyclically distributed in a synchronous protocol.

The position and time measurements are relative to the GPS antenna locations, not the ISS center of gravity. The conversion from the GPS antenna coordinate system to the ISS center of gravity is anticipated to be insignificant. This topic in addition to several others would be investigated following the approval for construction of a flight instrument.

Positional Accuracy

The positional measurements provide SHORE the basic orbital position information. The early ISS program requirements for position vector accuracy called for a probability of 99.73 percent that the RSS error would be less than 914 m. The R4 release of GN&C software greatly improves the accuracy to less than 6 m per axis.

Accuracy in the position vector affects SHORE pointing by translating the announced position some delta from the actual position. The translational errors create a bias/offset effect of the line of sight of SHORE as it is moved along the IJK axes. An error of 6 m creates an equivalent bias/offset error of 6 m at the target for the error components perpendicular to the SHORE line of sight. The SHORE requirement of absolute pointing accuracy calls for less than $\frac{1}{4}$ the FOV. This equates to 4 km. The positional error is well within the SHORE requirement. The error component along the SHORE line of sight has a negligible effect on the image.

Velocity Accuracy

The velocity measurement provides SHORE the orbital velocity information. The early ISS program requirements for velocity called for on-orbit translational state knowledge with a semi-major axis error less than 1000 feet (305 meters) 3-sigma. The R4 release of GN&C software improves the accuracy of coasting flight accuracy to less than 20 meters.

Accuracy in the velocity vector affects pixel smear. The velocity errors create variation in the relative velocity of the line of sight and the target. An error of 20 m creates a variation in the slewing velocity of the 454.5 m/s required rate. The SHORE requirement calls for less than 15 m of smear (one pixel). As long as the pointing system used by SHORE can provide a slewing velocity of 434.5 m/s, the requirement can be met.

Attitude Accuracy

Initial ISS attitude determination was accurate to within 0.25 degrees. SIGI firmware improved the accuracy to 0.1 degrees per axis. During more extreme maneuvers and events (docking, momentum wheel dump, etc.), attitude variations will exceed this accuracy. However, the more significant events are planned and can therefore be addressed in SHORE operational scheduling.

The effect of the accuracy of the attitude measurements manifests as rotational errors in SHORE pointing. These errors are more problematic due to the long distances and small FOV of SHORE. A 0.1 degree rotation error in an attitude axis equates approximately to a similar 0.1 degree error in SHORE pointing. The SHORE specification for absolute pointing accuracy calls for less than $\frac{1}{4}$ the FOV. The SHORE FOV is 2.5 degrees, therefore any attitude variation less than 0.625 degrees meets the requirement.

Timing Accuracy

ISS time is based on GPS time. Accuracy following the SIGI firmware update is within 20-50 microseconds. Collection and distribution of time in BAD packets are delayed due to routing. The delay could be in the range of 2 seconds. It has not been determined what the characteristics are of the variability in this distribution delay.

The effect of time errors could be a significant factor for SHORE. The satellite sub-point is moving at 7.25 km/s, the SHORE requirement is for less than $\frac{1}{4}$ the FOV variation. To meet the SHORE requirement, time must be accurate to not less than 0.55 seconds. The time distribution delay will need to be characterized to fully assess the error effects.

Conclusion

The ISS orbital state measurement knowledge meets the SHORE requirements with a yet to be determined effect of the time distribution delay. The position, velocity and attitude services meet the SHORE requirements with margin. The accumulative effects of the errors will be fully evaluated in a flight instrument development program.

7. ISS DISTURBANCES

The pointing budget elements discussed in this section are shown in the figure 18 below.

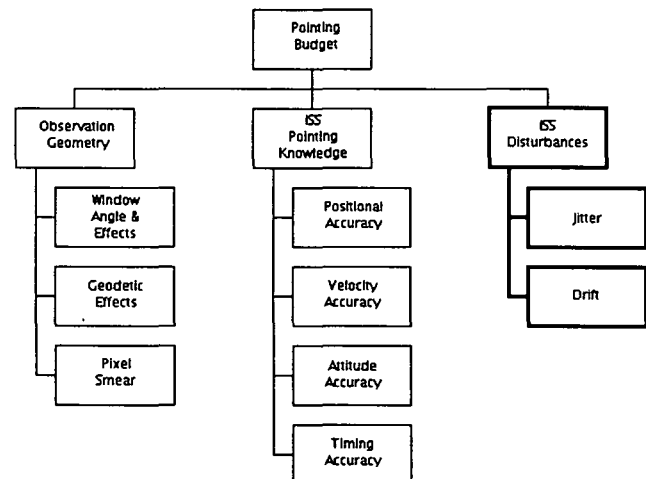


Figure 18 – Pointing Budget Factors.

Space Station has many disturbance sources ranging from large (i.e. docking, momentum wheel dumps, re-boost) to small (i.e. crew push-offs, vent valve cycling, CMG noise). The larger disturbances are usually known in advance and can be planned into the SHORE operations schedule. The smaller disturbances may occur without prior knowledge.

The disturbance environment is characterized by models and on board accelerometer measurements. There are two models available; an overall ISS model and the WOLF model. The WOLF model is built upon the ISS model therefore incorporating the overall ISS disturbance environment. The WOLF model is a NASTRAN dynamic FEM model providing modal frequency data from 0.1 to 300 Hz. The model is built utilizing 20,900 nodes and 23,600 elements. The large ISS model is complex and involved. It aggregates hundreds of disturbance sources into response

frequencies up to 50 Hz. It is fortunate that instrument developers can utilize the WOLF model to keep the analysis task manageable.

The WOLF model allows the analysis of different instrument designs and the resulting disturbance results. Since SHORE is in the prototype stage and a physical design is not available, the FEM capabilities of the model were not used. The WOLF model also provides disturbance data for window viewing instruments positioned on the optical bench. The disturbances at the WOLF optical bench are on the order of 19 micro-radians in each axis. This is the data used for this analysis applied to the SHORE prototype.

The accelerometer measurements are collected in the U.S. Laboratory Module, the same module in which WOLF is located. The accelerometer data has been collected over a substantial period and would likely be utilized in the analysis for an approved flight instrument development. A detailed analysis has not been performed to compare the models and accelerometer data.

Effects of Disturbances

The disturbance levels of 19 micro-radians have the effect of adding an angular component of error to the SHORE pointing. The rotational error component offsets the azimuth and elevation pointing. The SHORE requirements for relative pointing stability include jitter and drift. The jitter requirement is for less than $\frac{1}{4}$ a pixel during the integration period (33 ms). The drift requirement is for less than $\frac{1}{4}$ a pixel during the image acquisition period (90 s).

The angle subtended by a 15 m pixel seen from SHORE at a height of 386 km is 40 micro-radians. At a disturbance level of 19 micro-radians, it's almost half a pixel. SHORE will incorporate passive damping into the design of a flight instrument. A reduction of at least 2 in jitter is expected with the passive damping. The contribution of errors by the disturbances is a key factor in the SHORE design. Passive damping is the goal of the instrument due to the considerable increase in cost and complexity accompanying active damping systems. The drift requirement is expected to be acceptable due to the apparent drift stability of ISS and measurement knowledge.

8. CONCLUSION

This paper investigated and analyzed topics related to using the International Space Station for a remote sensing platform for a SHORE type instrument. The analysis looked at an approach to convert the target position into instrument pointing knowledge. Also pointing budget margins were preliminarily analyzed. Figure 19 summarizes the pointing budget findings. The solid boxed factors are fully within the SHORE requirements. The dashed boxes are within the

requirements but will be closely reviewed in the flight development phase.

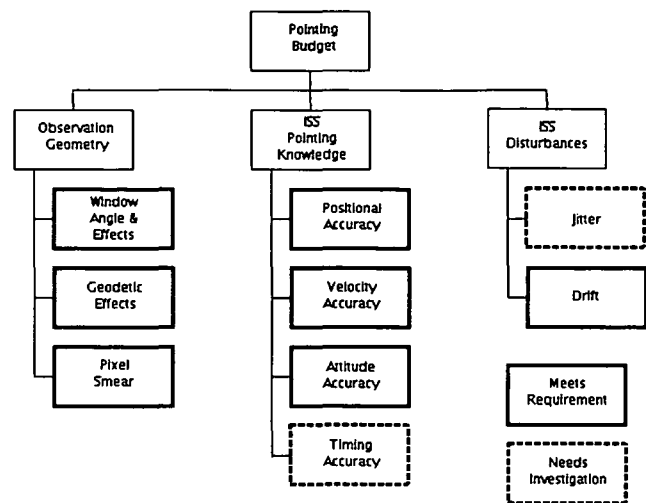


Figure 19 – Pointing Budget Summary.

Analysis Results

The analysis shows promise for SHORE observations from ISS. The delay in time measurement routing is an open issue that will need to be resolved. The results from this analysis support continued work to develop the prototype. However, the areas investigated in this paper are a preliminary analysis and subset of a full analysis required for developing an instrument capable of performing on Space Station.

SHORE instrument prototyping continues at Florida Institute of Technology. This analysis support continued work towards characterizing the proposed SHORE approach and consideration of a flight instrument development program.

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BIOGRAPHY

Craig Jacobson is a project manager and systems engineer at NASA, Kennedy Space center. He is currently involved in the Constellation Program supporting the development of ground systems capabilities for the testing and launch of the Ares I launch vehicle and Orion spacecraft. He has led the operations and user communities for checkout, ground and communications systems for the development of systems and capabilities to support Shuttle and Space Station payload and science instruments. He has performed assembly and checkout of Shuttle Spacelab flight experiments and scientific instruments. He has a BSEE from South Dakota School of Mines and Technology and a master's in Aerospace Engineering from the University of Central Florida. He is moving more into areas related to research and analysis in space systems and science.

