922-20007003

M3 Profiling Data Format

Document revisions

Version	Date	Written by	Checked by	Approved by
1.0	Sep. 16, 2013	AZ	CS	BC
1.1	Mar. 06, 2014	AZ	CS	BC
1.2	Sep. 25, 2014	AZ	JR/RH	BC
1.3	Jun. 01, 2015	AZ	CS	BC
1.4	Oct 24, 2016	JR	AZ	RH

About this document

The information contained in this document is subject to change without prior notice.

Kongsberg Mesotech Ltd. shall not be liable for errors contained herein, or for incidental or consequential damages in connection with the furnishing, performance, or use of this document.

Kongsberg Mesotech Ltd.

1598 Kebet Way
Port Coquitlam, BC
V3C 5M5 Canada

Telephone: +1 604 464 8144
Telefax: +1 604 941 5423
www.kongsberg-mesotech.com
Email: km.sales.vancouver@kongsberg.com

KONGSBERG

Table of Contents

Document history

Version 1	First release.
Version 1.1	Error correction in Data Body. Added wReserved1 and wReserved2 for data alignment
Version 1.2	Added shAmp10dB for sample amplitude, removed fProfile_I and fProfile_Q
Version 1.3	Added fSoundSpeed_RT
Version 1.4	added sRealTimeSoundSpeed and removed fSoundSpeed_RT added fAlitude and fHeightGeoidAbvEllipsoid added new fields to support the .ALL format (sGPSQualityParas , bBeamSpacingIdentifier, bSoundSpeedSource; bTimeSyncMode, bTxPulseType, fVesselSOG) Added new fields (byQualityFactor, byDetectionInfo and wDetWinLenSamples) in the profiling data body to support the .ALL format

1 PMB DATA FORMAT

1.1 Common data type

Data Type	Description
int16	16-bit signed integer
int32	32-bit signed integer
unsigned int16	16-bit unsigned integer
unsigned int32	32-bit unsigned integer
Float	32-bit floating point
Double	64-bit floating point
Char	8 bit character
Byte	8 bit unsigned integer

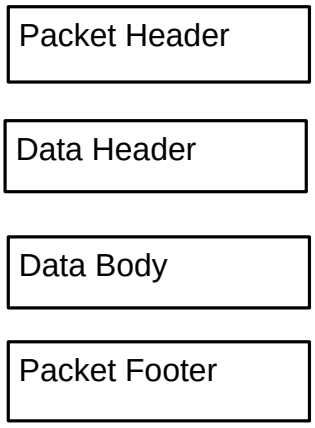
1.2 Constant Structure

Structure	Fields	Data type	Description
MUM_TVG_PARAMS	factorA	unsigned int16	factor A, the spreading coefficient
	factorB	unsigned int16	factor B, the absorption coefficient in dB/km
	factorC	float	factor C, the TVG curve offset in dB
	factorL	float	factor L, the maximum gain limit in dB
M3_OFFSETS	xOffset	float	Translational offset in X axis
	yOffset	float	Translational offset in Y axis
	zOffset	float	Translational offset in Z axis
	xRotOffset	float	Rotational offset about X axis in degrees (Pitch offset)
	yRotOffset	float	Rotational offset about Y axis in degrees (Roll offset)
	zRotOffset	float	Rotational offset about Z axis in degrees (Yaw offset)
	dwMounting	unsigned int32	Mounting orientation. Fixed head mounting parameters from the Deployment

			Configuration, for information only. The mounting orientation is fully described by the xRotOffset, yRotOffset and zRotOffset fields. If dwVersion < 5 0: mounting Down or Aft 1: mounting Up or Fore If dwVersion >=5 0: Custom; 1: Forward; 2: Forward Inverted; 3: Roll Right; 4: Roll Left; 5: Upward; 6: Upward Inverted; 7: Downward; 8: Downward Inverted
M3_ROTATOR_OFFSETS	fOffsetA	float	Rotator offset A in meters
	fOffsetB	float	Rotator offset B in meters
	fOffsetR	float	Rotator offset R in meters
	fAngle	float	Rotator angle in degrees
REAL_TIME_SOUND_SPEED	fRaw	float	Raw sound speed in m/s directly from sensor readings
	fFiltered	float	Filtered sound speed in m/s after a median filter on the raw values
	fApplied	float	Applied sound speed in m/s after the filtering and thresholding, and will be used for sonar data processing
	fThreshold	Float	A user predefined threshold in m/s used to get the applied value
GPS_QUALITY_PARAS	wQualIndicator	unsigned int16	GPS quality indicator
	wNSat	unsigned int16	Number of Satellites in use
	fHorizDilution	float	Horizontal dilution of precision
	wPosFixQualityCm	unsigned int16	Position fixed quality in cm
	wReserved	unsigned int16	Reserved field to keep the structure aligned

1.3 Data structure

The data packets are packed with packet header and packet footer for data integrity purpose.



1.4 Profile Range and Bearing. Data Type 0x1008

1.4.1 Packet Header Prefix

Size	Type	Description
2 bytes	unsigned int16	Synchronization word, always 0x8000
2 bytes	unsigned int16	Synchronization word, always 0x8000
2 bytes	unsigned int16	Synchronization word, always 0x8000
2 bytes	unsigned int16	Synchronization word, always 0x8000
2 bytes	unsigned int16	Data type, always 0x1008
2 bytes	unsigned int16	Reserved field
40 bytes	unsigned int32[10]	40 reserved bytes
4 bytes	unsigned int32	Packet body size.

1.4.2 Packet Footer

Size	Type	Description
4 bytes	unsigned int32	Packet body size.
40 bytes	unsigned int32[10]	40 Reserved bytes

1.4.3 Data integrity checking procedure

Check the "Synchronization word" 0x8000, 0x8000, 0x8000, 0x8000

"Packet body size" in "Packet Header" and "Packet Footer" should be the same.

1.4.4 Packet body Description

Packet body contains Data Header and Data Body.

1.4.4.1 Data Type 0x1008 Data Header

Data Header is an n bytes long field prefixed to the data body.

Field	Item size (bytes)	Data type	Description
dwProfiling_Data_Version	4	unsigned int32	Version of this header. Current version 10.
dwSonarID	4	unsigned int32	Sonar identification – indicates Head number in Deployment Configuration, 0 for first Head
dwSonarInfo[8]	32	unsigned int32[8]	Sonar information such as serial number, power up configurations. Head ID in first 4 bytes.
dwModeID	4	unsigned int32	Unique mode ID for sonar app and range
dwPRI_ID	4	unsigned int32	Unique PRI identification
dwPingCounter	4	unsigned int32	Ping counter. Rolls back to zero if reaches 0xFFFFFFFF
dwTimeSec	4	unsigned int32	Timestamp of current ping in seconds elapsed since midnight (00:00:00), January 1, 1970. UTC
dwTimeMillisec	4	unsigned int32	Milliseconds part of current ping.
fVelocitySound	4	float	Speed of sound in m/s
fCompassHeading	4	float	Deploy Config Reference Heading in decimal degrees. This could come from an external heading sensor.
fMagneticVariation	4	float	Magnetic variation in decimal degrees. East is positive.
fPitch	4	float	Deploy Config Reference Pitch in decimal degrees. This could come from an external motion sensor.
fRoll	4	float	Deploy Config Reference Roll in decimal degrees. This could come from an external motion sensor.

dbLatitude	8	double	Latitude of current ping in decimal degrees. North is positive.
dbLongitude	8	double	Longitude of current ping in decimal degrees. East is positive.
fLocalTimeOffset	4	float	Local time zone offset in decimal hours relative to UTC.
fInternalSensorHeading	4	float	Compass heading in decimal degrees from the Head internal sensor (may or may not be the same as fCompassHeading).
fInternalSensorPitch	4	float	Pitch angle in decimal degrees from the Head internal sensor (may or may not be the same as fPitch).
fInternalSensorRoll	4	float	Roll angle in decimal degrees from the Head internal sensor (may or may not be the same as fRoll).
sOffSets	28	M3_OFFSETS	M3 deployment configuration including translational and rational offsets and mounting information
sAxesRotatorOffsets[3]	48	M3_ROTATOR_ OFFSETS[3]	Rotator offsets for a rotator mounted on the M3 system at Axis 1, 2 and 3.
fDepth	4	float	Deploy Config Reference Depth in decimal meters.
fTemperature	4	float	Sonar head temperature in decimal Celsius.
fTXWST	4	float	Tx Window Start Time in seconds.
fSWST	4	float	Sampling Window Start Time in seconds.
fSampleInterval	4	float	Sample interval in seconds.
dwSonarFreq	4	unsigned int 32	Sonar frequency in Hz.
dwNumSamples	4	unsigned int 32	Total number of image range samples.
nNumBeams	2	unsigned int16	Total number of beams.
bBeamSpacingIdentifier	1	byte	Beam spacing identifier. 0: FFT beamformer, 1: Equidistant, 2: Equiangle, 3: high density equidistant, 4: high density processing
bSoundSpeedSource	1	byte	Source of the sound speed. 0: real time sensor, 1: user manually entered.
fNearRangeMeter	4	float	Minimum range of source image in meters.
fFarRangeMeter	4	float	Maximum range of source image in meters.
dwProfileAlgorithm	4	unsigned int32	Profiling Algorithm used to extract the profile points.
fProfileParameters[8]	32	float	Profiling parameters 0 to 7.

dwPulseLength	4	unsigned int32	Transmit pulse length in microseconds.
fRXFilterBW	4	float	RX filter bandwidth in Hz
sTVGParameters	12	MUM_TVG_PARAMS	TVG parameters
wPulseType	2	unsigned int16	Tx pulse type. 0: CW, 1: FM up sweep, 2: FM down sweep.
bTimeSyncMode	1	byte	Timer synchronization mode. 1: free running, 2: 1PPS, 4: NTP, 8: host synchronization
bReserved	1	byte	Reserved field
fAltitude	4	float	Altitude in decimal meters.
fHeightGeoidAbvEllipsoid	4	float	Ellipsoid height in meters.
fHeave	4	float	Heave in meters.
fReserved	4	float	Reserved.
sRealTimeSoundSpeed	16	REAL_TIME_SOUND_SPEED	A structure containing the raw, filtered, applied sound speed and the sound speed threshold, for both external sensor readings and the fixed value.
sGPSQualityParas	12	GPS_QUALITY_PARAS	GPS quality parameters.
fVesselSOG	4	float	Vessel Speed Over Ground in knots
Reserved	440	byte	440 reserved bytes

1.4.4.2 Data Body

Repeat cycle nNumBeams entries of:			A list of angles for all beams up to the number of beams specified in nNumBeams field.
nBeamNumber	2	unsigned int 16	The current beam number, zero indexed. (0 to nNumBeams -1)
wReserved1	2	unsigned int 16	Reserved field
fBeamAngle	4	float	The current beam angle in degrees.
nNumOfProfilePoints	2	unsigned int 16	Number of profile points.
wReserved2	2	unsigned int 16	Reserved field
Repeat cycle nNumOfPoints entries of:			A list of profile point samples for each beam up to the number of profile points specified in nNumOfProfilePoints field.
fProfileSampleNo	4	float	The decimal sample number of the profile point that can be used to calculate the profile point distance in meters. See Note 1.

fBeamAngleOffset	4	float	Angular offset from beam centre in decimal degrees
shAmp10dB	2	int16	Sample amplitudes in 0.1 dB (Example: -30.2 dB stored as -302 = 0xFED2)
shReserved	2	int 16	Reserved field for phase
byQualityFactor	1	byte	Quality factor = 2500*sd/dr, where sd is the standard deviation (sd) of the range detection and dr is the detected range. Set to 0 if no valid detection for this beam in M3. Used by .ALL format
byDetectionInfo	1	byte	Detection information defined by .ALL. 0x01: valid phase detection; 0x00: valid amplitude detection. 0x84: invalid detection.
wDetWinLenSamples	2	unsigned int16	Detection window length in samples. Set to 0 if no valid detection for this beam.
End of Repeat cycle nNumOfPoints			
End of Repeat cycle nNumBeams			

1.4.4.3 Note 1:

How to calculate profile distance P(S) in meters:

P(S)=((fSWST–fTXWST) + fSampleInterval*fProfileSampleNo)*fVelocitySound/2

1.5 Water Column Data, Amplitude and Phase. Data Type 0x2001

1.5.1 Packet Header Prefix

Size	Type	Description
2 bytes	unsigned int16	Synchronization word, always 0x8000
2 bytes	unsigned int16	Synchronization word, always 0x8000
2 bytes	unsigned int16	Synchronization word, always 0x8000
2 bytes	unsigned int16	Synchronization word, always 0x8000
2 bytes	unsigned int16	Data type, always 0x2001
2 bytes	unsigned int16	Reserved field
40 bytes	unsigned int32[10]	40 reserved bytes
4 bytes	unsigned int32	Packet body size.

1.5.2 Packet Footer

Size	Type	Description
4 bytes	unsigned int32	Packet body size.
40 bytes	unsigned int32[10]	40 Reserved bytes

1.5.3 Packet body Description

Packet body contains Data Header and Data Body.

1.5.3.1 Data Type 0x2001/0x2002 Data Header

Field	Item size (bytes)	Data type	Description
dwVersion	4	unsigned int32	Version of this header. Current version 10. This header has a fixed length of 288 bytes and is always identical to the first 288 bytes of the profiling header described above.
dwSonarID	4	unsigned int32	Sonar identification – indicates Head number in Deployment Configuration, 0 for first Head
dwSonarInfo[8]	32	unsigned int32[8]	Sonar information such as serial number, power up configurations. Head ID in first 4 bytes.
dwModeID	4	unsigned int32	Unique mode ID for sonar app and range
dwPRI_ID	4	unsigned int32	Unique PRI identification
dwPingCounter	4	unsigned int32	Ping counter. Rolls back to zero if reaches 0xFFFFFFFF
dwTimeSec	4	unsigned int32	Timestamp of current ping in seconds elapsed since midnight (00:00:00), January 1, 1970. UTC
dwTimeMillisec	4	unsigned int32	Milliseconds part of current ping.
fVelocitySound	4	float	Speed of sound in m/s
fCompassHeading	4	float	Deploy Config Reference Heading in decimal degrees. This could come from an external heading sensor.
fMagneticVariation	4	float	Magnetic variation in decimal degrees. East is positive.
fPitch	4	float	Deploy Config Reference Pitch in decimal degrees. This could come from an external motion sensor.
fRoll	4	float	Deploy Config Reference Roll in decimal degrees. This could come from an external motion sensor.
dbLatitude	8	double	Latitude of current ping in decimal degrees. North is positive.
dbLongitude	8	double	Longitude of current ping in decimal degrees. East is positive.

fLocalTimeOffset	4	float	Local time zone offset in decimal hours relative to UTC.
fInternalSensorHeading	4	float	Compass heading in decimal degrees from the Head internal sensor (may or may not be the same as fCompassHeading).
fInternalSensorPitch	4	float	Pitch angle in decimal degrees from the Head internal sensor (may or may not be the same as fPitch).
fInternalSensorRoll	4	float	Roll angle in decimal degrees from the Head internal sensor (may or may not be the same as fRoll).
fXOffset	4	float	Translational offset in X axis in decimal meters. Deploy Config fixed Head Mounting Parameter.
fYOffset	4	float	Translational offset in Y axis in decimal meters. Deploy Config fixed Head Mounting Parameter.
fZOffset	4	float	Translational offset in Z axis in decimal meters. Deploy Config fixed Head Mounting Parameter.
fXRotOffset	4	float	Rotational offset about X axis (Pitch offset) in decimal degrees. Deploy Config fixed Head Mounting Parameter.
fYRotOffset	4	float	Rotational offset about Y axis (Roll offset) in decimal degrees. Deploy Config fixed Head Mounting Parameter.
fZRotOffset	4	float	Rotational offset about Z axis (Yaw offset) in decimal degrees. Deploy Config fixed Head Mounting Parameter.
dwMounting	4	unsigned int	Mounting orientation: 0: Custom 1: Forward 2: Forward Inverted 3: Roll Right 4: Roll Left 5: Upward 6: Upward Inverted 7: Downward 8: Downward Inverted Deploy Config Head Mounting Parameter. For information only; mounting orientation is fully described by the fXRotOffset, fYRotOffset and fYRotOffset fields.
sRotatorParameters1	16	M3_ROTATOR_OFFSETS	Axis 1 Rotator offsets and angles.

sRotatorParameters2	16	M3_ROTATOR_OFFSETS	Axis 2 Rotator offsets and angles.
sRotatorParameters3	16	M3_ROTATOR_OFFSETS	Axis 3 Rotator offsets and angles.
fDepth	4	float	Deploy Config Reference Depth in decimal meters.
fTemperature	4	float	Sonar head temperature in decimal Celsius.
fTXWST	4	float	Tx Window Start Time in seconds.
fSWST	4	float	Sampling Window Start Time in seconds.
fSampleInterval	4	float	Sample interval in seconds.
dwSonarFreq	4	unsigned int 32	Sonar frequency in Hz.
dwNumSamples	4	unsigned int 32	Total number of image range samples.
nNumBeams	2	unsigned int16	Total number of beams.
wReserved1	2	unsigned int16	Reserved field
fNearRangeMeter	4	float	Minimum range of source image in meters.
fFarRangeMeter	4	float	Maximum range of source image in meters.
dwProfileAlgorithm	4	unsigned int32	Profiling Algorithm used to extract the profile points.
fProfileParameters[8]	32	float	Profiling parameters 0 to 7.
dwPulseLength	4	unsigned int32	Transmit pulse length in microseconds.
fRXFilterBW	4	float	RX filter bandwidth in Hz
sTVGParameters	12	MUM_TVG_PARAMS	TVG parameters
wPulseType	2	unsigned int16	TX pulse type: 0, CW. 1, LFM
wReserved	2	unsigned int16	Reserved field
Repeat cycle nNumBeams entries of:			A list of angles for all beams up to the number of beams specified in nNumBeams field.
dwNumSamples_ Amplitude	4	unsigned int 32	Number of samples of amplitude data retained
dwStartSample_Amplitude	4	unsigned int 32	Starting amplitude sample
dwNumSample_Phase	4	unsigned int32	Number of samples of phase data retained. Set to zero if there's no phase data (for data type 0x2002)
dwStartSample_Phase	4	unsigned int 32	Starting phase sample. Set to zero if there's no phase data (for data type 0x2002)
fBeamAngle	4	float	The current beam angle in degrees.
End of Repeat cycle nNumBeams			
Reserved	100	byte	100 reserved bytes

1.5.3.2 Data Body

The Packet body contains water column sample amplitudes and two sub array phase differences used in split-beam profiling.

$A_{0s}\ A_{0s+1}$ ..... $A_{0(s+n-1)}$

$Q_{0S}\ Q_{0S+1}$ ..... $Q_{0(S+N-1)}$

$A_{1s}\ A_{1s+1}$ ..... $A_{1(S+n-1)}$

$Q_{1S}\ Q_{1S+1}$ ..... $Q_{1(S+N-1)}$

. .

. .

. .

$A_{(m-1)s}$ ..... $A_{(m-1)(s+n-1)}$

$Q_{(m-1)S}$ ..... $Q_{(m-1)(S+N-1)}$

Where:

A = 16 bits signed integer in 0.1 dB. (Example: -30.2 dB stored as -302 = 0xFED2)

Q = 16 bits signed integer in 0.0001 radians. (Example: -3.1415 stores as 31415= 0x7AB7)

m = Total number of beams, declared in field nNumBeams

s = Start of the amplitude sample for each beam, declared in dwStartSample_Amplitude field

n = Total number of amplitude samples, declared in dwNumSamples_ Amplitude field

S = Start of the phase sample for each beam, declared in dwStartSample_Phase field

N = Total number of phase samples, declared in dwNumSample_Phase field

1.6 Water Column Data. Amplitude only. Data Type 0x2002

1.6.1 Packet Header Prefix

Size	Type	Description
2 bytes	unsigned int16	Synchronization word, always 0x8000
2 bytes	unsigned int16	Synchronization word, always 0x8000
2 bytes	unsigned int16	Synchronization word, always 0x8000
2 bytes	unsigned int16	Synchronization word, always 0x8000

2 bytes	unsigned int16	Data type, always 0x2002
2 bytes	unsigned int16	Reserved field
40 bytes	unsigned int32[10]	40 reserved bytes
4 bytes	unsigned int32	Packet body size.

1.6.2 Packet Footer

Size	Type	Description
4 bytes	unsigned int32	Packet body size.
40 bytes	unsigned int32[10]	40 Reserved bytes

1.6.3 Packet body Description

Packet body contains Data Header and Data Body.

1.6.3.1 Data Header

See 1.5.3.1 Data Type 0x2001/0x2002 Data Header for details.

1.6.3.2 Data Body

The Packet body contains water column sample amplitudes

$$
\begin{array}{lll}
A_{0s}\ A_{0s+1} & \ldots\ldots\ldots\ldots & A_{0(s+n-1)} \\
A_{1s}\ A_{1s+1} & \ldots\ldots\ldots\ldots & A_{1(S+n-1)} \\
\cdot & & \cdot \\
\cdot & & \cdot \\
\cdot & & \cdot \\
A_{(m-1)s} & \ldots\ldots\ldots\ldots & A_{(m-1)(s+n-1)}
\end{array}
$$

Where:

A = 16 bits signed integer in 0.1 dB. (Example: -30.2 dB stored as -302 = 0xFED2)

m = Total number of beams, declared in field nNumBeams

s = Start of the amplitude sample for each beam, declared in dwStartSample_Amplitude field

n = Total number of amplitude samples, declared in dwNumSamples_ Amplitude field

2 COORDINATE SYSTEMS

This section describes the coordinate systems used in deployment configuration and related activities, including generation of 3D point clouds from ping and rotator data.

2.1 Sonar Coordinate System

The Sonar Coordinate System {S} is fixed to the face of the sonar as indicated in **Figure 1**. When the sonar is mounted in the commonly used "Forward" orientation on a vehicle, Z_S will point up, Y_S will point forward and X_S will point to starboard.

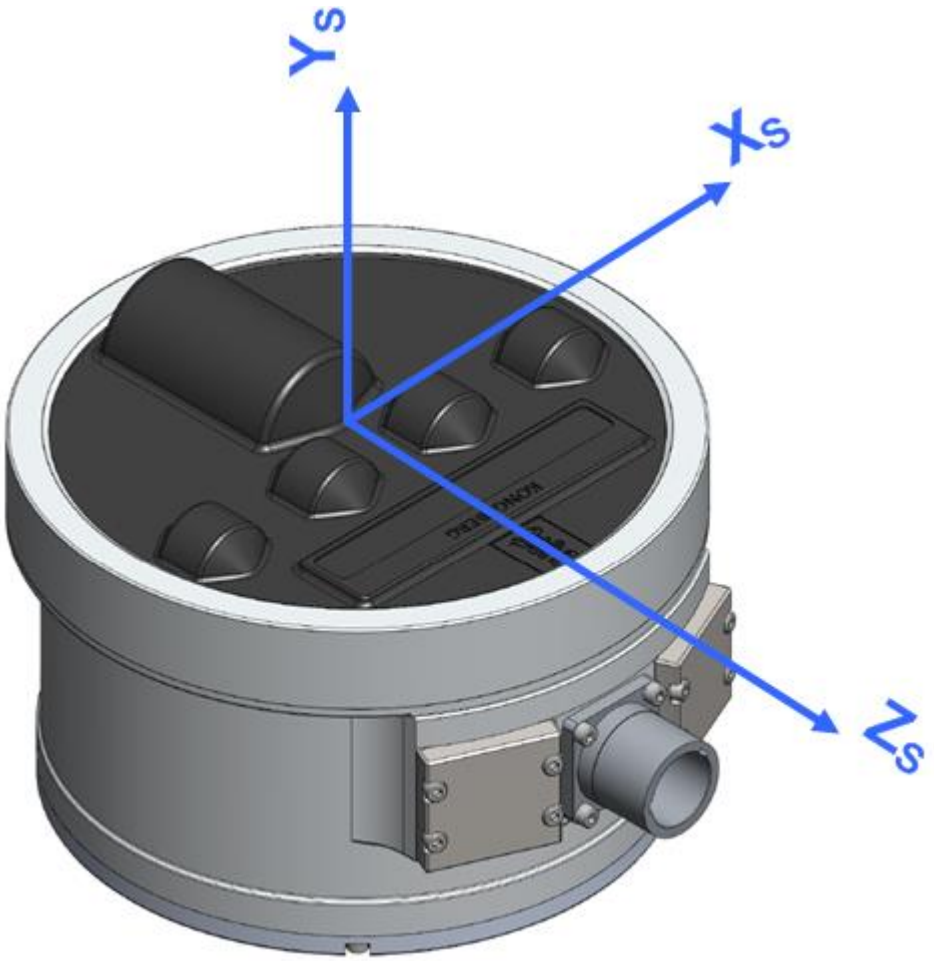


Figure 1: Sonar Coordinate System {S}

2.2 Reference Coordinate System

The Reference Coordinate System {0} is a right-handed Cartesian coordinate system (X_0, Y_0, Z_0) fixed with respect to the sonar platform (e.g., the ROV, tripod or pole-mount). By convention, Y_0 points forwards and Z_0 points upwards.

2.3 Sonar Mounting Parameters

The sonar mounting parameters describe the position of the Sonar Coordinate System {S} with respect to the Reference Coordinate System {0} as shown in **Figure 2**. There are three translational parameters (X offset, Y offset, Z offset) and three rotational parameters (pitch, roll, yaw), which are applied in a translate-then-rotate fashion.

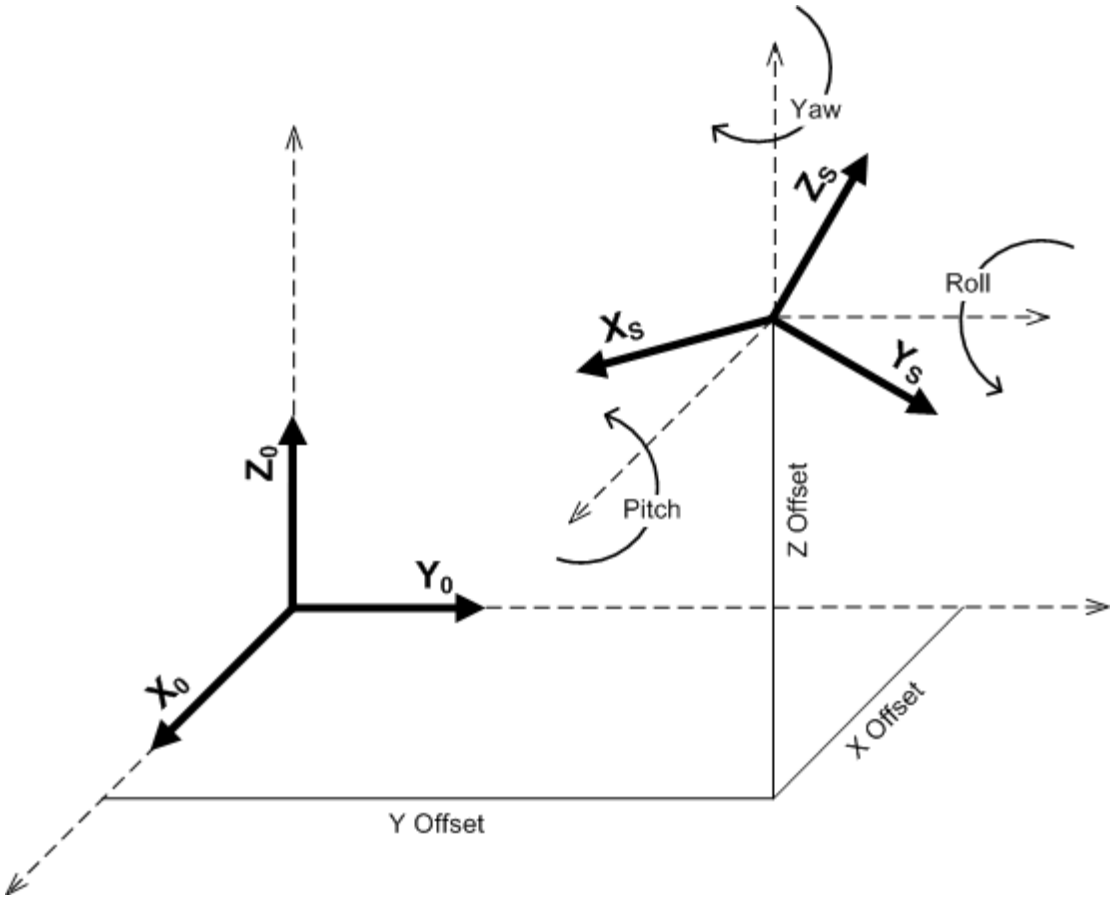


Figure 2: Sonar Mounting Parameters

2.4 Coordinate Transformations

Coordinate transformations are defined by translation and rotation parameters (angles).

The following matrix equation describes the transformation of a point P in {S} coordinates to point P in {0} coordinates:

$$^{O}P = {}^{O}_{S}R\ {}^{S}P + {}^{O}P_{SORG}$$

where:

^{O}P is point P with respect to {0},

^{S}P is point P with respect to {S},

${}^{O}_{S}R$ is the rotation of {S} with respect to {0}, and

$^{O}P_{SORG}$ is the origin of {S} with respect to {0}.

In terms of the transformation parameters, $^{O}P_{SORG}$ is a 3 X 1 vector containing the translation parameters, and ${}^{O}_{S}R$ is a 3 X 3 rotation matrix that generated from the three rotation parameters.

The matrix equation for the inverse transformation is given by

$$^{S}P = {}^{S}_{O}R\left(^{O}P - {}^{O}P_{SORG}\right)$$

Rotation is defined in terms of *X-Y-Z fixed angles*, where the word "fixed" refers to the fact that the rotations are specified about the fixed (non-moving) reference frame. In *X-Y-Z fixed angles*, the rotations are carried out in the following order:

1. Rotate {S} about $\hat{X}_O$ by γ
2. Rotate {S} about $\hat{Y}_O$ by β
3. Rotate {S} about $\hat{Z}_O$ by α

Rotation direction is clockwise when looking in the direction of it respective axis (right-hand rule). For the sonar mounting rotational parameters: pitch = γ; roll = β; and yaw = $-\alpha$.

The {S} to {0} rotation matrix is defined

$$ {}^{O}_{S}R \;=\; R_Z(\alpha)\, R_Y(\beta)\, R_X(\gamma) = \begin{bmatrix} r_{11} & r_{12} & r_{13} \\ r_{21} & r_{22} & r_{23} \\ r_{31} & r_{32} & r_{33} \end{bmatrix} $$

where:

$$ r_{11} = \cos\alpha \cos\beta $$
$$ r_{21} = \sin\alpha \cos\beta $$
$$ r_{31} = -\sin\beta $$
$$ r_{12} = \cos\alpha \sin\beta \sin\gamma - \sin\alpha \cos\gamma $$
$$ r_{22} = \sin\alpha \sin\beta \sin\gamma + \cos\alpha \cos\gamma $$
$$ r_{32} = \cos\beta \sin\gamma $$
$$ r_{13} = \cos\alpha \sin\beta \cos\gamma + \sin\alpha \sin\gamma $$
$$ r_{23} = \sin\alpha \sin\beta \cos\gamma - \cos\alpha \sin\gamma $$
$$ r_{33} = \cos\beta \cos\gamma $$

Section 2.6 contains C++ sample code showing coordinate transformation implementation.

2.4.1 Comparing Transformations

Two transformations may be compared by calculating the norm of the difference between the two points resulting from transforming a common input point separately by each of the transformations.

$$ {}^{A}P \;=\; {}^{O}_{A}T\, {}^{O}P $$

$$ {}^{B}P \;=\; {}^{O}_{B}T\, {}^{O}P $$

$$ d \;=\; \left\| {}^{A}P \;-\; {}^{B}P \right\| $$

The norm d gives a measure of "distance" between transformations ${}^{O}_{A}T$ and ${}^{O}_{B}T$ for the common input point ${}^{O}P$. Two or more separate input points are required to give a proper measure of "distance" between transformations; a single point will indicate zero distance for an infinite number of transformation pairs. Note, this matrix notation combines the rotation matrix and translation vector of the transformation.

2.5 Rotator Axes and Offsets

Up to three rotator axes are supported in the deployment configuration. Each rotator axis is defined relative to the sonar coordinate system (X_S, Y_S, Z_S) in term of System Axes:

1. System Axis 1 is parallel to X_S when rotator angles on axes 2 and 3 are zero
2. System Axis 2 is parallel to Y_S when rotator angles on axes 1 and 3 are zero
3. System Axis 3 is parallel to Z_S when rotator angles on axes 1 and 2 are zero

See **Figure 1** for details of the sonar coordinate system (X_S, Y_S, Z_S).

Each rotator axis is defined relative to the sonar coordinate system in terms of rotator offsets A, B and R as shown in **Figure 3**, **Figure 4** and **Figure 5** for each of the three system axes. **Figure 6** and Table 1 describe coordinate transformations in terms of the rotator offsets and angles (see Section 2.6 for a corresponding C++ code example).

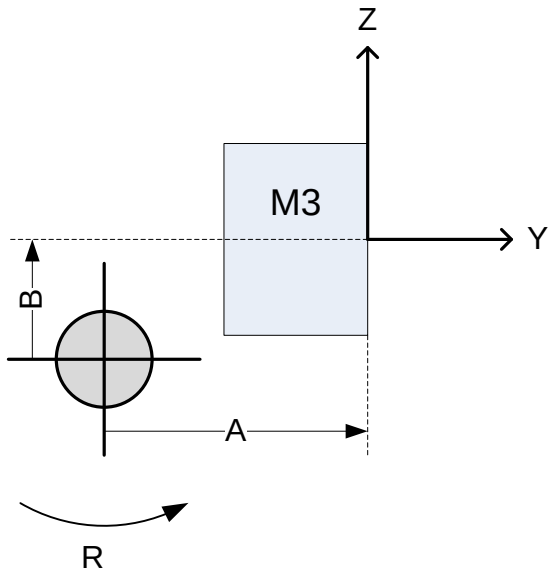


Figure 3: Rotator Offsets for System Axis 1

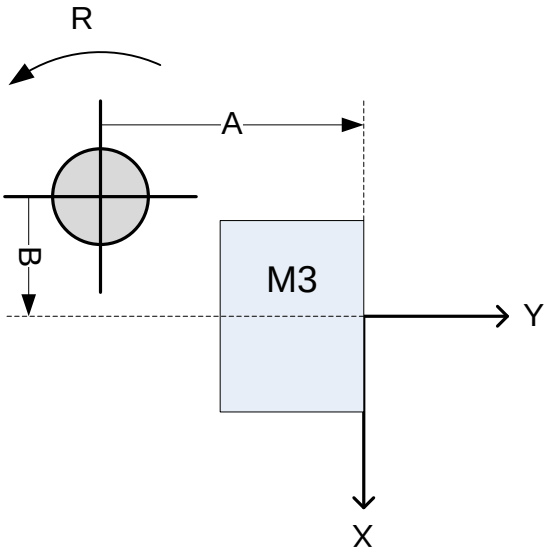


Figure 4: Rotator Offsets for System Axis 2

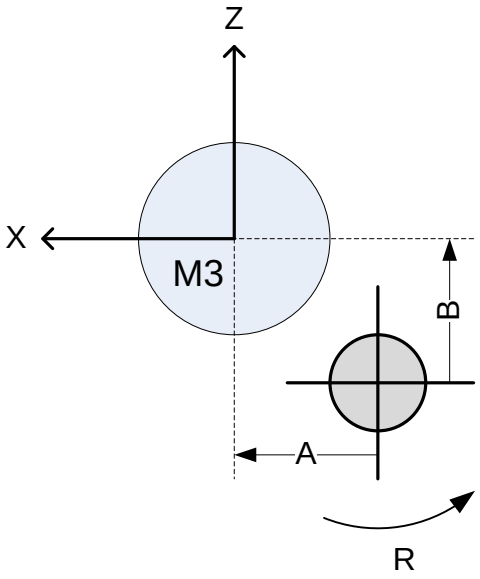


Figure 5: Rotator Offsets for System Axis 3

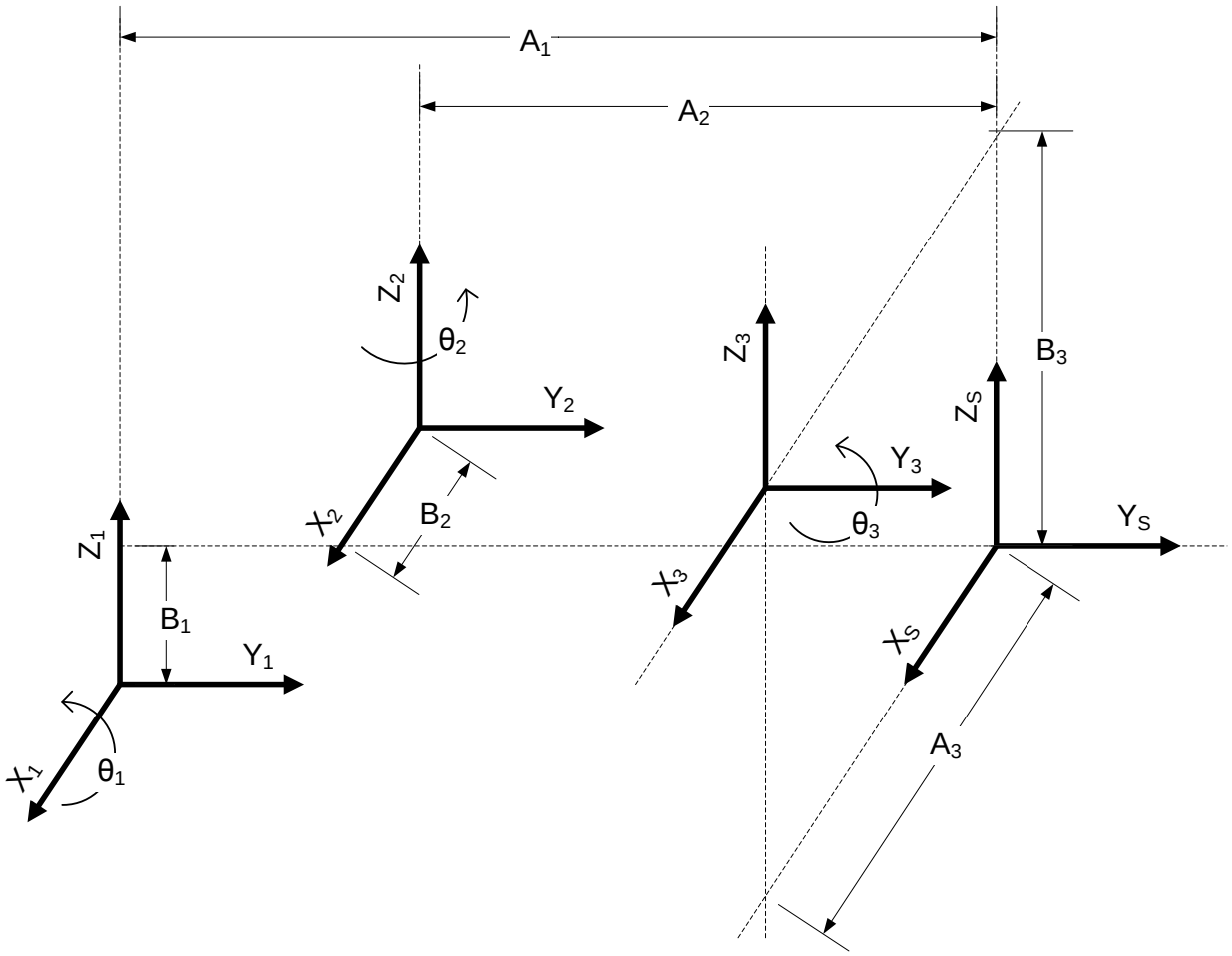


Figure 6: Rotator Offsets and Angles

Table 1: Coordinate Transformations in terms of Rotator Offsets

	${}^{S}_{1}T$	${}^{1}_{2}T$	${}^{2}_{3}T$	${}^{3}_{S}T$	${}^{1}_{S}T_{0}$
Δx	$-B_2$	0	$B_2 + A_3$	$-A_3$	B_2
Δy	$-A_1$	$A_1 - A_2$	A_2	0	A_1
Δz	$-B_1$	B_1	B_3	$-B_3$	B_1
γ	θ_1	0	0	0	0
β	0	0	θ_3	0	0
α	0	θ_2	0	0	0

2.6 Sample Code for Coordinate Transformation

2.6.1 CoordSys Header

```
// CoordSys.h

class CoordSys
{
public:

  CoordSys(double x,
           double y,
           double z,
           double gamma,
           double beta,
           double alpha);

  ~CoordSys(void);

  void Concat(const CoordSys& B);
  void Transform(double& x, double& y, double& z) const;
  void Matrix( GLfloat matrix[ 16 ] );

  //--------------------------------------------------------------------------
  // Norm -- designed for use in comparing transforms. The norm returned by
  // this function is a measure of "distance" between transforms in the
  // direction specified by the input vector.
  //
  // Returns the norm ||r_a - r_b||, where
  //
  //   r_a is the transformation of vector r by this transform
  //   r_b is the transformation of vector r by transform B
  //   r is the input vector specified by (x,y,z)
  //
  //--------------------------------------------------------------------------
  //
```

```
  double Norm(const CoordSys& B, const double x, const double y, const double z)
const;

private:
  CoordSys();


private:
  double P_org[3];
  double R_xyz[3][3];

};
```

2.6.2 CoordSys Source

```
// CoordSys.cpp

#include "CoordSys.h"
#include <cmath>

#define DEG2RAD (double)0.017453292519943

CoordSys::CoordSys(double x,
                   double y,
                   double z,
                   double gamma,
                   double beta,
                   double alpha)
{
    P_org[0] = x;
    P_org[1] = y;
    P_org[2] = z;

    double sin_a = sin(alpha*DEG2RAD);
    double sin_b = sin(beta*DEG2RAD);
    double sin_g = sin(gamma*DEG2RAD);
```

```
    double cos_a = cos(alpha*DEG2RAD);
    double cos_b = cos(beta*DEG2RAD);
    double cos_g = cos(gamma*DEG2RAD);

    R_xyz[0][0] = cos_a*cos_b;
    R_xyz[1][0] = sin_a*cos_b;
    R_xyz[2][0] = -sin_b;

    R_xyz[0][1] = cos_a*sin_b*sin_g - sin_a*cos_g;
    R_xyz[1][1] = sin_a*sin_b*sin_g + cos_a*cos_g;
    R_xyz[2][1] = cos_b*sin_g;

    R_xyz[0][2] = cos_a*sin_b*cos_g + sin_a*sin_g;
    R_xyz[1][2] = sin_a*sin_b*cos_g - cos_a*sin_g;
    R_xyz[2][2] = cos_b*cos_g;
}

CoordSys::~CoordSys(void)
{
}

void CoordSys::Concat(const CoordSys& B)
{
    int i, j = 0;

    // Make local copy of the rotation matrix
    double R[3][3];

    for (i = 0; i < 3; i++)
    {
        for (j = 0; j < 3; j++)
        {
            R[i][j] = R_xyz[i][j];
        }
    }
```

```
    // Loop over rows
    for (i = 0; i < 3; i++)
    {
        P_org[i] =
            R[i][0]*B.P_org[0] +
            R[i][1]*B.P_org[1] +
            R[i][2]*B.P_org[2] +
            P_org[i];

        for (j = 0; j < 3; j++)
        {
            R_xyz[i][j] =
                R[i][0]*B.R_xyz[0][j] +
                R[i][1]*B.R_xyz[1][j] +
                R[i][2]*B.R_xyz[2][j];
        }
    }
}

void CoordSys::Transform(double& x, double& y, double& z) const
{
    double t[3];

    for (int i = 0; i < 3; i++)
    {
        t[i] = R_xyz[i][0]*x + R_xyz[i][1]*y + R_xyz[i][2]*z + P_org[i];
    }

    x = t[0];
    y = t[1];
    z = t[2];
}

double CoordSys::Norm(const CoordSys& B, const double x, const double y, const
double z) const
{
  double a_x = x;
```

```
  double a_y = y;
  double a_z = z;

  double b_x = x;
  double b_y = y;
  double b_z = z;

  this->Transform(a_x, a_y, a_z);
  B.Transform(b_x, b_y, b_z);

  double distance = sqrt( (a_x - b_x)*(a_x - b_x) +
                          (a_y - b_y)*(a_y - b_y) +
                          (a_z - b_z)*(a_z - b_z) );

  return distance;

}

void CoordSys::Matrix( GLfloat matrix[ 16 ] )
{
   #define M( x, y )  matrix[ x + y * 4 ]

   M( 0, 0 ) = (GLfloat)R_xyz[0][0];
   M( 1, 0 ) = (GLfloat)R_xyz[1][0];
   M( 2, 0 ) = (GLfloat)R_xyz[2][0];
   M( 3, 0 ) = (GLfloat)0.0;

   M( 0, 1 ) = (GLfloat)R_xyz[0][1];
   M( 1, 1 ) = (GLfloat)R_xyz[1][1];
   M( 2, 1 ) = (GLfloat)R_xyz[2][1];
   M( 3, 1 ) = (GLfloat)0.0;

   M( 0, 2 ) = (GLfloat)R_xyz[0][2];
   M( 1, 2 ) = (GLfloat)R_xyz[1][2];
   M( 2, 2 ) = (GLfloat)R_xyz[2][2];
   M( 3, 2 ) = (GLfloat)0.0;
```

```
   M( 0, 3 ) = (GLfloat)0.0;
   M( 1, 3 ) = (GLfloat)0.0;
   M( 2, 3 ) = (GLfloat)0.0;
   M( 3, 3 ) = (GLfloat)1.0;
}
```

2.6.3 Sample Usage of CoordSys

```
#include "CoordSys.h"

  // ...

  CoordSys T_RS(xOffset, yOffset, zOffset,  pitch,   roll,   -yaw);
  CoordSys T_S1(    -b2,     -a1,     -b1, theta1,    0.0,    0.0);
  CoordSys T_12(    0.0, a1 - a2,      b1,    0.0,    0.0, theta2);
  CoordSys T_23(b2 + a3,      a2,      b3,    0.0, theta3,    0.0);
  CoordSys T_3S(    -a3,     0.0,     -b3,    0.0,    0.0,    0.0);
  CoordSys T_1S(     b2,      a1,      b1,    0.0,    0.0,    0.0);

  T_RS.Concat(T_S1);
  T_RS.Concat(T_12);
  T_RS.Concat(T_23);
  T_RS.Concat(T_3S);
  T_RS.Concat(T_1S);

  for (int i = 0; i < numPoints; ii++)
  {
    T_RS.Transform(x[i], y[i], z[i]);
  }

  // .
```