S500

Inertial Wave Sensor

User Manual

NEXSENS technology

About NexSens

NexSens is a US-based company specializing in the design and manufacture of real-time environmental measurement systems. Recent data logger, sensor and web developments simplify collecting and sharing project data. Environmental measurement systems are constructed with standard components. Data is transmitted by WiFi, cellular, satellite or radio and shared on a real-time datacenter.

Planning

Component and system drawings are available online

Integration

Systems are pre-constructed, tested and documented prior to shipment

Field Services

Installation support and setup ensure successful deployments

Training

Factory or onsite training ensure successful startup and operation

Repair

Technicians inspect and recondition equipment for reliable performance

Support

Online knowledge base, phone and email support are readily available

Table of Contents

Overview **1**

What's Included **2**

Common Accessories 2

Specifications **3**

General 3

Wave 3

Wave Output 4

Getting Started **5**

Under Water (UW) Connections 5

LED Indicators 5

Sampling Configuration 6

Connecting to a NexSens Data Logger 7

Connecting to any RS-485 Modbus RTU Device 8

UW-R FL Cable Connections 8

Sensor Information 9

Register Information 9

Universal Address 9

S500 Sensor Buoy Mounting 10

Calibration 10

Pre-Deployment Check 11

Mooring 11

Maintenance **12**

Cleaning 12

Storage 12

Troubleshooting **13**

Warranty and Service **14**

Appendix A – Modbus Registers **15**

Read Input Registers (Function 0x04) 15
Preset Single Register (Function 0x06) 19
Preset Multiple Registers (Function 0x10) 20
Notes 21
Examples 22
Appendix B – Magnetometer Calibration 24
Overview 24
3D Calibrations...25
2D Calibration 25
Modbus Calibration Procedure 26
Calibration Status Information 26
Appendix C – Parameter Explanation 27
Appendix D – Wave Calculation Theory 29

Overview

The S500 wave measurement system integrates a high accuracy inertial sensor to capture wave motion with next generation electronics for data storage and processing. The S500 internal Inertial Measurement Unit (IMU) employs three gyroscopes, three magnetometers, and three accelerometers to provide raw motion data acquisition with 6-degrees of freedom. The powerful on-board ARM microcontroller performs raw data analysis in order to provide both directional and non-directional statistical wave output.

Raw wave motion data and calculated wave parameters are retained using the onboard SD-Card to allow for later in-depth analysis. The S500 communicates with a host controller or data logger using the industry standard RS-485 Modbus RTU protocol.

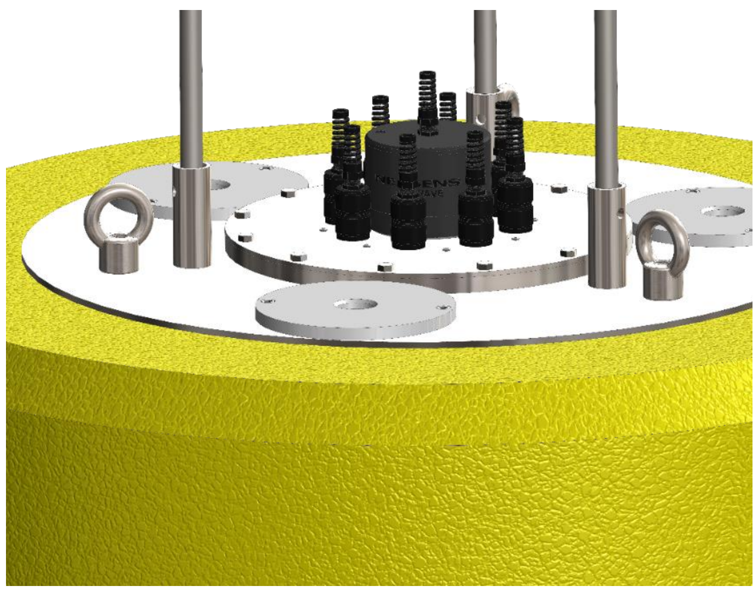

Figure 1: Wave Sensor Buoy Mounting

What’s Included

Each S500 Wave Sensor includes the O-rings required for preventing leakage and cracking at mountings and connections as well as necessary mounting hardware and tooling.

- S500 Wave Sensor
- Shock absorbing 149 O-ring
- (2) ¼-20 x ½” Hex mounting screws
- 3/16” Hex Driver

Common Accessories

NOTE

The S500 uses a unique NexSens UW Underwater Connector for interfacing with accessories.

Table 1: Accessories commonly used with S500 temperature sensors

Part Number	Description	Details
RS485-RS232	RS-485 to RS-232 Adapter	RS-232 to RS-485 signal converter with UW receptacle connector and flying lead interface for interfacing to user’s logger
UW-FL1R	Underwater to flying lead cable adapter	Used to connect S500 wave sensor to a user’s logger

Specifications

General

Table 2: NexSens S500 Wave Sensor General Specifications

Height	3.75 in. (95.25 mm) - Not including cable or strain relief
Diameter (OD)	5 in. (127 mm)
Weight	2 lbs.
Housing	Body - Polyvinylchloride (PVC) Lid - Acrylic
Operating Temp Range	-20-70 °C
Output	RS-485 Modbus RTU
Power Requirements	Voltage: 5 to 28 VDC
Power Consumption	Average Active: 850mW (~70mA @ 12V)
Storage	2GB Industrial SD-Card (Expandable to 8G)

Wave

Table 3: NexSens S500 Wave Measurement Specifications

Heave	Range: +/- 25 meters Resolution: 0.01 meters Accuracy: 0.1 meters OR 10% (Whichever is higher)
Period	Range: 2.5 to 33 seconds Resolution: 0.1 seconds
Direction	Range: 0 to 359 degrees Resolution: 1 degree
Wave Motion Sampling Frequency	1, 2, 4, 5, or 10 Hz
Wave Motion Acquisition Period	7, 14, 17, 34,or 68 minutes

Wave Output

Table 4: NexSens S500 Wave Parameter

Name	**Parameter**	**Unit**
Spectral Moment Wave Height (WVHT)	H_{M0}	Meters
Zero Crossing Wave Period (DPD)	T_P	Seconds
Average Wave Period (Zero Crossing Wave Period)	T_{02}	Seconds
Mean Wave Direction	Θ_M	Degrees
Significant Wave Height	H_S ($H_{1/3}$)	Meters
Top 10% Wave Height	$H_{1/10}$	Meters
Average Wave Height	H_{AVG}	Meters
Max Wave Height	H_{MAX}	Meters
Wave Period	T_S ($T_{1/3}$)	Seconds
Wave Period	$T_{1/10}$	Seconds
Zero Crossing Wave Period (APD)	T_{AVG} (T_Z)	Seconds
Wave Period	T_{P5}	Seconds
Number of Zero Crossings	N_Z	N/A
Wave Steepness	S	N/A
Mean Spread	Σ_M	Degrees

Getting Started

NOTE

Always check *each* mating connector for an O-ring before securing any UW underwater connection.

WARNING

All O-rings must be clean and dry before being used to secure watertight connections.

Under Water (UW) Connections

All NexSens sensors are fitted with UW connectors to allow for simple, secure, and watertight interfacing between devices.

UW cable ends include a flexible strain-relief and either a plug or receptacle fitting. Double O-rings (both gland and face seals) ensure a reliable and water-tight connection. Mated connectors are rated at 200 feet of submersion.

Cables are interchangeable and can be connected in series to extend lengths as needed.

LED Indicators

There are (4) LEDs visible through the S500's top acrylic plate. Figure 2 shows the LED locations and Table 5 summarizes their various behaviors.

Figure 2: LED Locations

Table 5: LED Actions

Status	LED Color	LED Action	Notes
Power Applied	Green	Solid during boot period	10 msec. duration
Power Stable	Red	Blink every 5 sec.	
Wave Data Collecting	Yellow	Blink every 2 sec.	
Wave Data Calculations	Blue	Blink every 2 sec.	External communication not available
Error	Red & Green	Solid	Cycle power

Sampling Configuration

The S500 can be configured for a variety of sampling rates.

Table 6: Sampling Rate

Sampling Frequency (Hz)	Resulting Length of Data	Modbus Setting
1	68 minutes 16 seconds	0
2	34 minutes 8 seconds	1
4	17 minutes 4 seconds	2 (default)
5	13 minutes 40 seconds	3
10	6 minutes 50 seconds	4

Connecting to a NexSens Data Logger

UW underwater connectors provide a plug-and-play interface for connection to NexSens data loggers.

Figure 3: CB Series Data Well

The S500 Wave Sensor can be connected to Port P0, P1, or P2. If connected to a switch power port (P1 or P2), ensure switch power is configured and enabled (Recommended 5-10 minute warm-up for directional wave parameters).

Connecting to any RS-485 Modbus RTU Device

S500 devices can also be connected to any device capable of reading RS-485 Modbus RTU by utilizing a UW-R FL Cable. Signal converters can also be used to interface with other protocols.

UW-R FL Cable Connections

The following shows the necessary connections for the S500 using a UW-R FL cable.

Table 7: UW-R FL Cable

Receptacle Pin	Wire Color	S500
1	**Green**	**RS-485 A**
2	**Blue**	**RS-485 B**
3	Brown	NC
4	**Red**	**5-28 VDC**
5	White	NC
6	Yellow	NC
7	**Black**	**GND**
8	Orange	NC

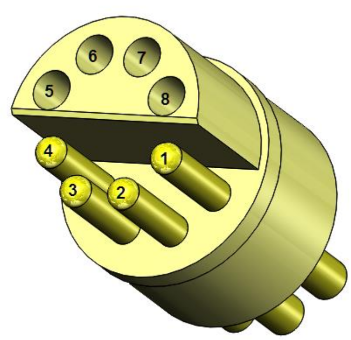

Figure 4: UW-Receptacle End

Sensor Information

The below information outlines the S500 sensor's communication requirements.

- Protocol: Modbus-RTU
- Baud Rate: 9600
- Parity: N81
- Default Address: 1
- Universal Address: 252
- Format: Big Endian
- Timeout: 500ms

Register Information

Please see Appendix A – Modbus Registers for a full list of registers.

Universal Address

The S500 is programmed such that any sensor will respond to Modbus address 252. This is implemented for the event that the sensor's current address is unknown. This address should only be queried with one device connected on the data line. If more than one device is connected, both will respond and a corrupted message is likely.

S500 Sensor Buoy Mounting

Install the included O-ring in the buoy's S500 mounting groove.

Figure 5: Install O-ring

Align the S500's screw holes with the mounting bracket and gently press down. Install the hex screws into the holes using the included driver to secure the S500 to the buoy.

Figure 6: Align Holes

Figure 7: Tighten Hex Screw

Calibration

For accurate directional wave measurements, sensor calibration is required. Please see Appendix B – Magnetometer Calibration for further details.

Pre-Deployment Check

It is recommended that field deployments be carefully planned, and it is best to completely configure the system on a lab bench and test it for a period of time prior to taking it to the field. This will ensure a successful deployment and quality data collection. Additionally, it is much easier to troubleshoot problems in the lab than in the field.

Mooring

While some applications can be untethered (free motion) others require a mooring solution. Mooring a buoy which is designed to measure wave motion requires special consideration and each mooring should be designed for that individual application. Consult a marine engineer for mooring design and simulation recommendations.

Key factors include:

- De-couple the mooring from the buoy to allow unrestricted motion so that the buoy can track waves
- Mooring line materials should be elastic (compliant) in order to limit any restrictions in movement
- Swivels and other mooring hardware should be selected to limit any restrictions in movement
- Any required buoy ballast weight should be engineered to limit motion restriction

Maintenance

There is very little maintenance required for S500 wave sensor because it is designed for long-term deployments in submersible applications.

Cleaning

Any bio-fouling that accumulates on the S500 during deployment should be cleaned using a soft cloth or soft-bristled brush along with soap and water.

Storage

The S500 should be stored in a cool, dry place.

Troubleshooting

Follow the procedure below to isolate and resolve sensor interface problems.

Table 8: S500 temperature sensor troubleshooting guide

Symptom	**Possible Cause**	**Corrective Action**
Wave data is displayed as a value between -99999 and -100001	No Power	Measure and correct any power issues
	Sensor disconnected (or severed cable)	Check the physical setup and condition of the cables
	Leakage into a connector	Check each underwater connection for flooding

If the issue persists, visit www.NexSens.com/Knowledgebase to search the Knowledge Base for Articles, FAQs and troubleshooting guides; otherwise please contact NexSens technical support.

Warranty and Service

NexSens Technology, Inc. warrants products against defects in materials or workmanship for a period of 12 months from the date of delivery to the original customer. This warranty is limited to the replacement or repair of such defects, without charge, when the product is returned to NexSens Technology, Inc. Damage due to accidents, misuse, tampering, lack of reasonable care, loss of parts, failure to perform prescribed maintenance, or accidents of nature are not covered. This warranty excludes all other warranties, express or implied, and is limited to a value not exceeding the purchase price of the instrument.

WARNING

NexSens Technology, Inc. products are not authorized for use as critical components in any life support system where failure of the product may affect its safety or effectiveness.

Limitation of Warranty

This warranty is not applicable to any NexSens Technology, Inc. product damage or failure caused by (i) failure to install, operate or use the product in accordance with NexSens Technology, Inc. written instructions, (ii) abuse or misuse of the product, (iii) failure to maintain the product in accordance with NexSens Technology, Inc. written instructions, (iv) any improper repairs to the product, (v) use by you of defective or improper components or parts in servicing or repairing the product, or (vi) modification of the product in any way not expressly authorized by NexSens Technology, Inc.

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Revision: 01 **Revision Code**: 16C28

Appendix A – Modbus Registers

Read Input Registers (Function 0x04)

Table 9: Modbus Read Input Registers

<table>
<tr><th>Command Name</th><th>Starting Register</th><th>Number Registers</th><th colspan="3">Command Description</th></tr>
<tr><td rowspan="3">Modbus Address</td><td rowspan="3">0x1000</td><td rowspan="3">1</td><td colspan="3">Returns the Modbus address</td></tr>
<tr><td>Register offset</td><td>Data Type</td><td>Parameter</td></tr>
<tr><td>0</td><td>u16</td><td>Modbus Address (1-247)</td></tr>
<tr><td rowspan="3">Sampling Frequency</td><td rowspan="3">0x3000</td><td rowspan="3">1</td><td colspan="3">Returns the sampling frequency of the sensor. Returns 0, 1, 2, 3, or 4.</td></tr>
<tr><td>Register offset</td><td>Data Type</td><td>Parameter</td></tr>
<tr><td>0</td><td>u16</td><td>Coded Sampling Frequency
0: 1Hz
1: 2Hz
2: 4Hz
3: 5Hz
4: 10Hz</td></tr>
<tr><td rowspan="8">Position and Date</td><td rowspan="8">0x3001</td><td rowspan="8">9</td><td colspan="3">Returns the position and date used to calculate magnetic declination.</td></tr>
<tr><td>Register offset</td><td>Data Type</td><td>Parameter</td></tr>
<tr><td>0</td><td>f</td><td>Latitude (Degrees)</td></tr>
<tr><td>2</td><td>f</td><td>Longitude (Degrees)</td></tr>
<tr><td>4</td><td>f</td><td>Altitude (meters)</td></tr>
<tr><td>6</td><td>u16</td><td>Day</td></tr>
<tr><td>7</td><td>u16</td><td>Month</td></tr>
<tr><td>8</td><td>u16</td><td>Year</td></tr>
<tr><td rowspan="3">DAQ Status</td><td rowspan="3">0x300A</td><td rowspan="3">1</td><td colspan="3">Returns 1 if a wave parameter DAQ is in progress.
Returns 0 if idle.</td></tr>
<tr><td>Register offset</td><td>Data Type</td><td>Parameter</td></tr>
<tr><td>0</td><td>u16</td><td>DAQ status</td></tr>
<tr><td>Calibration</td><td>0x300C</td><td>1</td><td colspan="3">Returns 1 if the last performed calibration</td></tr>
</table>

<table>
<tr><td rowspan="3">Status</td><td rowspan="3"></td><td rowspan="3"></td><td colspan="3">was successful.
Returns 0 if the last performed calibration failed.</td></tr>
<tr><td>Register offset</td><td>Data Type</td><td>Parameter</td></tr>
<tr><td>0</td><td>u16</td><td>Calibration status</td></tr>
<tr><td rowspan="5">Calibration Status Details</td><td rowspan="5">0x300D</td><td rowspan="5">23</td><td colspan="3">Returns a detailed analysis of the last calibration performed.</td></tr>
<tr><td>Register offset</td><td>Data Type</td><td>Parameter</td></tr>
<tr><td>0</td><td>u16</td><td>Quality of points collected
0: Optimal quality – Quality points and motions detected
1: Good – Small deviations in magnetic field detected
2: Poor – Large magnetic deviations from possible external source
3: Invalid – Significant magnetic deviations, invalid motions, or insignificant motions</td></tr>
<tr><td>1</td><td>u16</td><td>Magnetic interference level
0: High trust – Enough remarkable data points collected
1: Medium trust – Few remarkable data points collected
2: Low trust – Data set not meaningful enough, even if quality high</td></tr>
<tr><td>2</td><td>u16</td><td>Movement information
0x01: Not enough valid magnetic points
0x02:Excessive magnetic interference
0x04: X motion issue (3D – not enough motion on X axis / 2D too much motion on X axis)
0x08: Y motion issue (3D – not enough motion on Y</td></tr>
</table>

					axis / 2D too much motion on Y axis) 0x10: Z motion issue (Not enough motion on Z axis) 0x20: Alignment issue with inertial frame
			3	f	Mean magnetic norm before calibration
			5	f	Standard deviation of magnetic norm before calibration
			7	f	Max magnetic norm error before calibration
			9	f	Mean magnetic norm after calibration
			11	f	Standard deviation of magnetic norm after calibration
			13	f	Max magnetic norm error after calibration
			15	f	Mean expected accuracy of heading (radians)
			17	f	Standard deviation of expected accuracy of heading (radians)
			19	f	Max expected accuracy of heading (radians)
			21	u16	Max # of points allowed
			22	u16	Current # of points collected
Wave Parameter Results	0x3024	30	Returns the full set of calculated wave parameters		
			Register offset	Data Type	Parameter
			0	f	Hm0 (WVHT) Wave height (m)
			2	f	Tp (DPD) Wave period (sec)
			4	f	Tz (APD) Mean spectral

					wave period
			6	f	Mean wave direction (deg)
			8	f	Hs Wave Height (m)
			10	f	H10 Wave Height (m)
			12	f	Havg Wave Height (m)
			14	f	Hmax Wave Height (m)
			16	f	Ts Wave Period (sec)
			18	f	T10 Wave Period (sec)
			20	f	Tavg Wave Period (sec)
			22	f	Tp5 Wave Period (sec)
			24	f	Num Zero Crossing
			26	f	Wave steepness
			28	f	Mean spread (Set to 0)
Seconds Until DAQ Completion	0x3042	1	Seconds until completion		
			Register offset	Data Type	Parameter
			0	u16	Seconds until completion
Current Number of Data Points Read	0x3043	1	Number of raw data points read from sensor (0 to 4096)		
			Register offset	Data Type	Parameter
			0	u16	Number of raw data points
Magnetometer and System Status Enable	0x3044	1	Returns if additional system information is returned from the sensor. Returns 1 if data is enabled. Returns 0 if data is disabled.		
			Register offset	Data Type	Parameter
			0	u16	System info output status
Magnetometer and System Status Read	0x3045	8	Returns information about the current magnetometer quality		
			Register offset	Data Type	Parameter
			0	f	Magnetometer X axis reading
			2	f	Magnetometer Y axis reading

			4	f	Magnetometer Z axis reading
			6	f	Norm of all magnetometers
			8	u32	General Status
			10	u32	Communication Status
			12	u32	Aiding Status

Preset Single Register (Function 0x06)

Table 10: Modbus Preset Single Register

Command Name	**Begin Register**	**Number Registers**	**Register offset**	**Data Type**	**Data Description**
Modbus Address	0x1000	1	0	u16	Set Modbus address (1-247)
Default Configuration	0x1005	1	0	u16	Sets the wave sensor configuration to its default state when the value 1 is written to the register
Sampling Frequency	0x3000	1	0	u16	Sets the sampling frequency of the sensor. Send 0, 1, 2, 3, or 4 to this register. 0: 1Hz 1: 2Hz 2: 4Hz 3: 5Hz 4: 10Hz
DAQ Status	0x300A	1	0	u16	Begins or stops a wave parameters data acquisition. Write 1 set start the DAQ. Write 0 to stop the DAQ. Writing 1 while the DAQ is in progress restarts the DAQ.
Calibration Start	0x300B	1	0	u16	Begins or stops a calibration for the sensor's magnetometers. Write 1 to start a 2D calibration. Write 2 to start a 3D

					calibration. Write 0 to stop the calibration and calculate the result.
Magnetometer and System Status Enable	0x3044	1	0	u16	Sets the system status output for the sensor. Write 1 to set the output. Write 0 to stop the output.

Preset Multiple Registers (Function 0x10)

Table 11: Modbus Preset Multiple Registers

<table>
<tr><th>Command Name</th><th>Starting Register</th><th>Number Registers</th><th colspan="3">Command Description</th></tr>
<tr><td rowspan="3">Modbus Address</td><td rowspan="3">0x1000</td><td rowspan="3">1</td><td colspan="3">Sets the modbus address</td></tr>
<tr><td>Register offset</td><td>Data Type</td><td>Parameter</td></tr>
<tr><td>0</td><td>u16</td><td>Modbus Address (1-247)</td></tr>
<tr><td rowspan="3">Default Configuration</td><td rowspan="3">0x1005</td><td rowspan="3">1</td><td colspan="3">Sets the wave sensor configuration to its default state when the value 1 is written to the register</td></tr>
<tr><td>Register offset</td><td>Data Type</td><td>Parameter</td></tr>
<tr><td>0</td><td>u16</td><td>Default configuration start command</td></tr>
<tr><td rowspan="3">Sampling Frequency</td><td rowspan="3">0x3000</td><td rowspan="3">1</td><td colspan="3">Returns the sampling frequency of the sensor. Returns 0, 1, 2, 3, or 4.</td></tr>
<tr><td>Register offset</td><td>Data Type</td><td>Parameter</td></tr>
<tr><td>0</td><td>u16</td><td>Coded Sampling Frequency
0: 1Hz
1: 2Hz
2: 4Hz
3: 5Hz
4: 10Hz</td></tr>
<tr><td rowspan="2">Position and Date</td><td rowspan="2">0x3001</td><td rowspan="2">9</td><td colspan="3">Sets the position and date used to calculate magnetic declination.</td></tr>
<tr><td>Register</td><td>Data</td><td>Parameter</td></tr>
</table>

<table>
<tr><td></td><td></td><td></td><td><table><tr><td>offset</td><td>Type</td><td></td></tr><tr><td>0</td><td>f</td><td>Latitude (Degrees)</td></tr><tr><td>2</td><td>f</td><td>Longitude (Degrees)</td></tr><tr><td>4</td><td>f</td><td>Altitude (meters)</td></tr><tr><td>6</td><td>u16</td><td>Day</td></tr><tr><td>7</td><td>u16</td><td>Month</td></tr><tr><td>8</td><td>u16</td><td>Year</td></tr></table></td></tr>
<tr><td>DAQ Status</td><td>0x300A</td><td>1</td><td>Returns 1 if a wave parameter DAQ is in progress.
Returns 0 if idle.<table><tr><td>Register offset</td><td>Data Type</td><td>Parameter</td></tr><tr><td>0</td><td>u16</td><td>DAQ status</td></tr></table></td></tr>
<tr><td>Calibration Status</td><td>0x300C</td><td>1</td><td>Returns 1 if the last performed calibration was successful.
Returns 0 if the last performed calibration failed.<table><tr><td>Register offset</td><td>Data Type</td><td>Parameter</td></tr><tr><td>0</td><td>u16</td><td>Calibration status</td></tr></table></td></tr>
<tr><td>Magnetometer and System Status Enable</td><td>0x3044</td><td>1</td><td>Returns if additional system information is returned from the sensor. Returns 1 if data is enabled. Returns 0 if data is disabled.<table><tr><td>Register offset</td><td>Data Type</td><td>Parameter</td></tr><tr><td>0</td><td>u16</td><td>System info output status</td></tr></table></td></tr>
</table>

Notes

- Modbus registers are specified as value to send (send the value '0x3000' to access register '0x3000')
- Modbus commands must request the complete group of registers. For example, all 30 registers must be requested for the get wave parameter command for successful transmission. Asking for a single register is not supported.
- If a start DAQ command is sent while a DAQ is already taking place, the DAQ will be restarted

- While the wave parameters are being calculated (approximately 10-20 seconds), the sensor's Modbus may be unresponsive
- Data Types
  - f: IEEE 754 float
  - u16: 16 bit unsigned integer
  - u32: 32 bit unsigned integer

Examples

- **Example 1**: Take a wave parameter reading from the sensor
  1. Send the start DAQ command (write Modbus register 0x300A with the value '1')
  2. Wait until the data is ready
     - Read the get seconds to completion register (read Modbus register 0x3042) for the seconds remaining until DAQ and calculation is completed. This register will return 0 when the data is ready.
     - Alternatively, read the get number of raw data points register (read Modbus register 0x3043) for the number of data points collected. This register will return 4096 when all data points have been collected and processed
  3. Send the wave parameter results command (read Modbus register 0x3024).
     - The resulting 15 floating point data parameters need to be parsed
- **Example 2**: Start data acquisition for Modbus address 1
  01,10,30,0A,00,01,02,00,01,57,39
- **Example 3**: Request seconds remaining until data is ready from Modbus address 1
  01,04,30,42,00,01,9E,DE
- **Example 4**: Request number of raw data points collected from Modbus address 1
  01,04,30,43,00,01,CF,1E
- **Example 5**: Read calculated wave parameters from Modbus address 1
  01,04,30,24,00,1E,3F,09
- **Example 6**: Set sample frequency to setting 2 for Modbus address 1
  01,10,30,00,00,01,02,00,02,17,92
- **Example 7**: Get current sample frequency from Modbus address 1
  01,04,30,00,00,01,3E,CA
- **Example 8**: Start 2D calibration for Modbus address 1
  01,10,30,0B,00,01,02,00,01,56,E8

- **Example 9**: Start 3D calibration for Modbus address 1
  01,10,30,0B,00,01,02,00,02,16,E9
- **Example 10**: Stop calibration and calculate results for Modbus address 1
  01,10,30,0B,00,01,02,00,00,97,28
- **Example 11**: Read calibration status from Modbus address 1
  01,04,30,0C,00,01,FE,C9
- **Example 12**: Read calibration detailed status from Modbus address 1
  01,04,30,0D,00,17,2E,C7
- **Example 13**: Set location and date for Modbus address 1
  Latitude: 39.782833 (0x421F219F → Hex conversion from Float)
  Longitude: -83.99366 (0xC2A7FCC1 → Hex conversion from Float)
  Altitude: 258.983 (0x43817DD3 → Hex conversion from Float)
  Date: 02 JAN 2016 (0x07E0 → Hex conversion of year from Float)

  01,10,30,01,00,09,12,42,1F,21,9F,C2,A7,FC,C1,43,81,7D,D3,00,02,00,01,07,E0,F0,80

Appendix B – Magnetometer Calibration

Overview

This sensor allows for both hard and soft iron magnetic compensation, which help to provide accurate directional wave parameters regardless of the structure and environment surrounding the sensor. Hard iron effects can be described as any distortion caused by magnets or anything that acts as a magnet. Soft iron effects can be described as any distortion caused by ferromagnetic objects placed in the vicinity of the sensor.

The main goal of the calibration procedure is to perform magnetic field measurements in many different orientations. This is done by rotating the device in different orientations to measure the magnetic field. If the device cannot freely rotate in all possible orientations, the calibration algorithm can easily cope with it, and the procedure will result in good precision in orientations that were covered. Depending on the mobility of the mounting for the wave sensor, 2D or 3D calibrations can be performed. The location and date of deployment can also be entered into the sensor to account for magnetic declination.

Warning: Before initiating the calibration procedure, the mounting structure should be firmly attached to the wave sensor unit

Warning: Before initiating the calibration procedure, it is recommended to put the device in a place free of external magnetic fields (more than 3 meters from any source of distortion). Keep in mind that a building structure generally contains steel and other sources of interference, as well as computers, chairs, desks, etc.

Note: Unique orientations and points are more important than obtaining the same points multiple times.

Note: A 3D calibration is preferred over a 2D calibration even if only 30 degrees of tilt can be achieved.

Note: the stop calibration command may be sent any number of times to calculate new calibration parameters without clearing previously collected calibration points. This may be helpful if the cause of the calibration failure was insufficient motion or insignificant calibration points.

3D Calibrations

For most applications, a 3D calibration will provide the performance in correcting for magnetic disturbances. To perform a 3D calibration, the sensor and mounting system should be rotated in the orientations expected from the application. Optimal data points are obtained at a rotational speed less than 360°/s. For wave applications, the mounting system should be rotated in a horizontal circle and then tilted at least to 30 degrees in various directions and rotated.

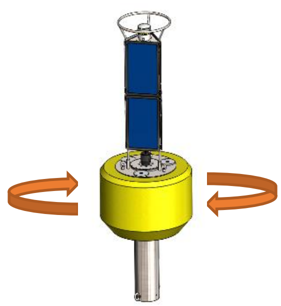

Figure 8: Rotate at 0°

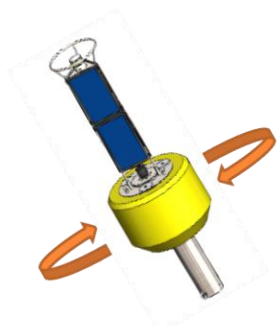

Figure 9: Rotate at -30°

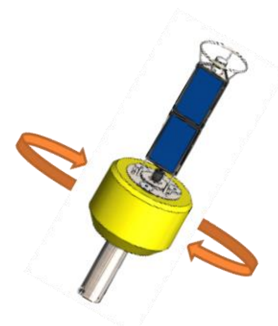

Figure 10: Rotate at 30°

2D Calibration

When motion of the system is restricted, a 2D calibration can be performed to make optimal use of the available data. The procedure for a 2D calibration involve rotating the device through a horizontal circle, while limiting any 3D movement. Although not required, best results are obtained from full 360° coverage. Compared to the 3D calibration, the 2D method may result in a residual offset to the heading, depending on the strength of nearby magnetic disturbances.

Warning: The 2D calibration requires accurate sensor position (Latitude, Longitude, and Altitude) and date information in order to work properly.

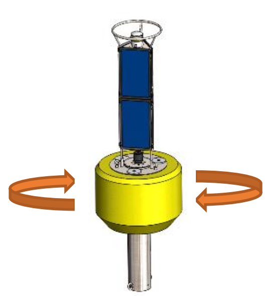

Figure 11: Rotate Horizontally

Modbus Calibration Procedure

1. For Modbus, the following steps should be followed:
2. Send the set position and date command for the current location of the calibration (write Modbus register 0x3001)
3. Send the start calibration command (write Modbus register 0x300B with a value of '1' for 2D calibration or with a value of '2' for 3D calibration)
4. Rotate the mounting structure and wave sensor in all possible positions that may be experienced in the application.
5. When rotations are completed, send the stop calibration command (write register 0x300B with a value of '0' to stop calibration)
6. Check the calibration status command (read Modbus register 0x300C)
    1. If the return value is '1', the calibration was successful
    2. If the return value is '0', the calibration failed
        1. Check the get calibration status detail command to determine the source of the error (read Modbus register 0x300D). See the *Calibration Status Information* for more details.
        2. Try the calibration again, making sure the area is free from any magnetic disturbances external to the mounting structure
7. If calibration is not done at the deployment location, send the set position and date command for the future deployment location and date

Calibration Status Information

The read calibration status register (Modbus register 0x300C) gives a response indicating success or failure of the calibration. For more information, the calibration status detail command (Modbus register 0x300D) should be used. This command returns 23 registers, which provide quality of calibration data points, detection of magnetic interference, and detail of rotational motion issues. These registers are described in Appendix A – Modbus Registers.

Additionally, the magnetometer and system status output can be enabled (write Modbus register 0x3044 with the value '1') to provide real time information about the magnetometer and heading status.

As a general rule, the following should be observed:

1. After a calibration when viewing the 0x300D registers, the 'quality of points collected' and 'magnetometer interference level' registers should read '0' or '1'. The 'movement information' register should read '0'.
2. If magnetometer and system output register is enabled, the 'norm of all magnetometers' register should read '1.0±0.01'.

Appendix C – Parameter Explanation

Table 12: Parameter Explanation

Name	Param.	Unit	Parameter Description
Spectral Moment Wave Height (WVHT)	H_{M0}	Meters	Significant wave height calculated from the spectral moments of frequency domain analysis. H_{M0} is equal to $4*\sqrt{(M0)}$
Zero Crossing Wave Period (DPD)	T_P	Seconds	Peak wave period calculated based on the highest peak of spectral energy
Average Wave Period (Zero Crossing Wave Period)	T_{02}	Seconds	Average wave period calculated from the spectral moments of frequency domain analysis. T_{02} is equal to $\sqrt{(M0/M2)}$
Mean Wave Direction	Θ_M	Degrees	Average wave direction calculated from spectral analysis
Significant Wave Height	H_S ($H_{1/3}$)	Meters	Average height of highest 33% of waves detected from time domain zero down-crossing wave analysis
Top 10% Wave Height	$H_{1/10}$	Meters	Average height of highest 10% of waves detected from time domain zero down-crossing wave analysis
Average Wave Height	H_{AVG}	Meters	Average height of all waves detected from time domain zero down-crossing wave analysis
Max Wave Height	H_{MAX}	Meters	Maximum wave height detected from time domain zero down-crossing wave analysis
Wave Period	T_S ($T_{1/3}$)	Seconds	Average wave period of the highest 33% of time domain zero down-crossing calculated waves
Wave Period	$T_{1/10}$	Seconds	Average wave period of the highest 10% of time domain zero down-crossing calculated waves
Zero Crossing Wave Period (APD)	T_{AVG} (T_Z)	Seconds	Average wave period calculated from average of all time domain zero down-crossing calculated waves
Wave Period	T_{P5}	Seconds	Peak wave period as computed by the Read Method. T_{P5} has less statistical variability than T_P because it is based on weighted spectral moments

Number of Zero Crossings	N_Z	N/A	Number of zero down-crossings detected during time domain analysis
Wave Steepness	S	N/A	Wave steepness, where '4' represents 'very steep', '3' represents 'steep', '2' represents 'average', '1' represents 'swell', and '0' represents a lack of meaningful wave data
Mean Spread (Set to 0)	Σ_M	Degrees	This is currently unimplemented.

Appendix D – Wave Calculation Theory

Overview

The S500 Wave Sensor contains a powerful IMU consisting of 3-axis iron-disturbance-resistant magnetometers, 3-axis accelerometers, and 3-axis low-noise gyroscopes. The calculated heave data has a marine model applied, which auto-adjusts to wave period for more accurate readings. The heave and angle data from the IMU is used to perform the following:

- Zero-crossing analysis for reporting time-domain wave period and wave height statistics
- Non-directional spectral analysis for reporting frequency domain wave period and wave height statistics
- Directional spectral analysis for reporting frequency domain wave direction and wave spread

Zero-crossing parameters are computed based on the locations of downward zero-crossings and peaks of the wave in between. These time domain statistics are useful for knowing exact values, such as the maximum wave height over a certain time frame; however, they are more susceptible to noise than frequency domain parameters.

Non-directional wave parameters are computed based on the frequency-domain representation of the heave motion data. The wave energy is summed over the spectrum in which significant waves can occur, typically including waves periods of 2 seconds up to 33 seconds. Non-directional wave parameters are based on statistics, indicating the likelihood of a wave above a certain threshold will be found in a data set. This analysis makes the wave parameters resistant to noise and can better capture the wave behavior over the measured time frame. Well documented approaches are used for finding non-directional wave parameters through use of spectral moments, which represent variance of the time series.

Directional wave parameters are computed based on the frequency-domain representation of both the surface elevation data and the angular motion data. Correlation is measured between the heave data series and east-west and north-south angular slopes. Based on these correlations, directional spectra are initially estimated by calculating directional coefficients from a limited Fourier Series. These coefficients are then further refined through approaches described in the references and used to produce mean wave direction and mean wave spread for the data set.

All calculations are fully performed on-board the wave sensor. Modbus RTU is supported to allow convenient changing of configurations and reading of calculated wave parameters. All raw and calculated data is logged to an on-board SD card for implementing user post-processing algorithms.

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