VSSP version 2.1 Specification

Volumetric Scanning Sensor Protocol

Version 1.0

Volumetric Scanning Sensor Project
Hokuyo Automatic Co., Ltd.

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Table of contents

General

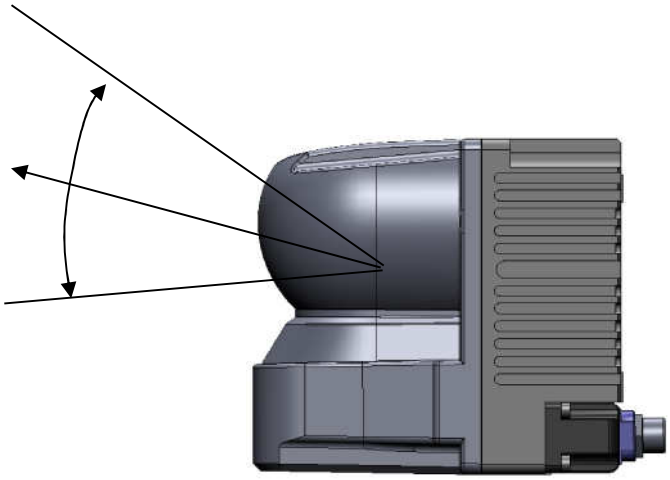
1.1 Communication method

TCP/IP are used as lower layer communication protocol. Therefore, error detection is not implemented in VSSP.

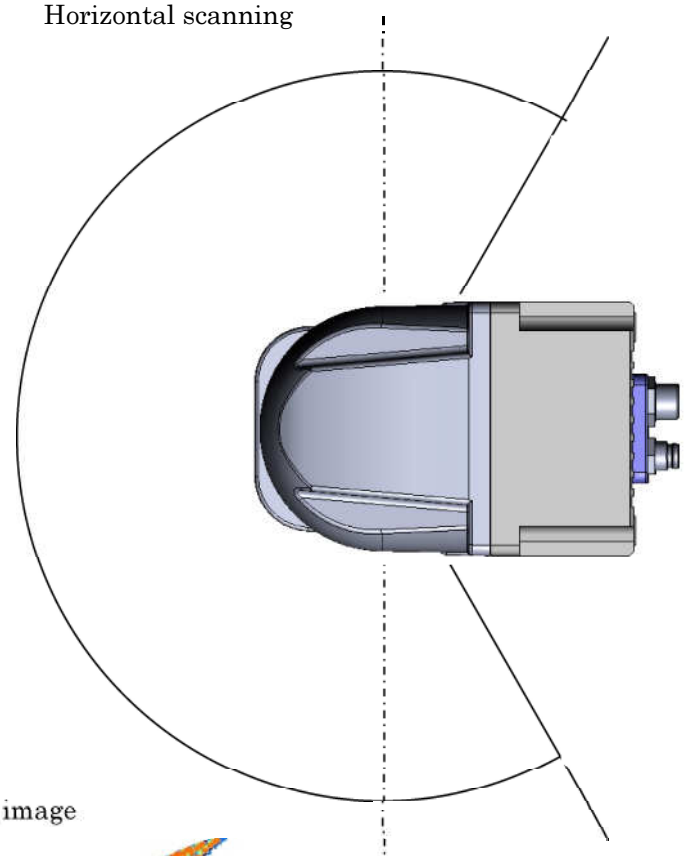
1.2 Measurement method

Volumetric scanning sensor protocol (VSSP) is designed for 3D scanning sensor. As shown in the figure below, the referred sensor has a combination of oscillating mirror and rotating motor to do respectively vertical and horizontal scanning.

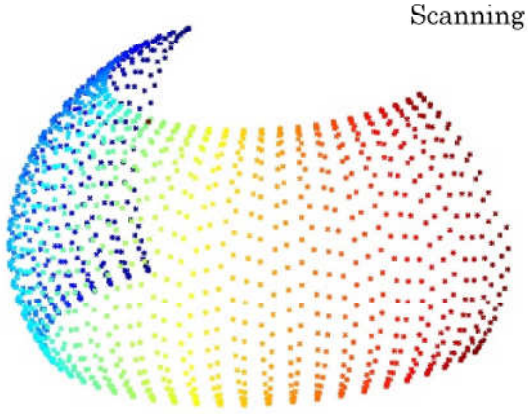
Vertical scanning



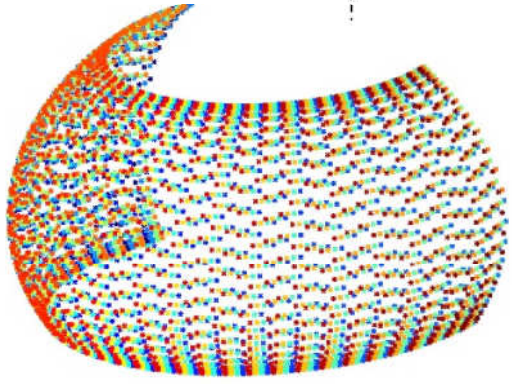
Horizontal scanning



Scanning image



Non-interlaced mode

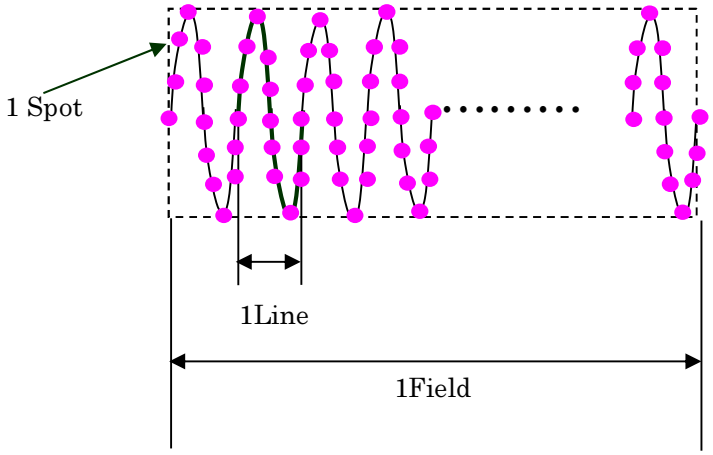


Interlaced mode

1.3 Data format

The measurement data obtained by scanning are listed below.

Name	Meaning
Echo	Measurement in one specific direction
Spot	Group of echos in one specific direction
Line	Spots of one vertical cycle
Horizontal Field	Lines of one horizontal cycle (VSSP 1.1 field)
Vertical Field	Horizontal fields of one vertical cycle (VSSP 2.0 function added)
Frame	Collection of one or multiple fields depending on the interlaced mode setting.(In case of non-interlaced mode, 1 Frame=1 Field)



1.4 Code format

Communication data consists of character and binary. Code format is defined as below.

Data code	Meaning
‘A’	1 character (byte) (Character A)
C(n)	n character (byte) variable string
LF	Line Feed= 0x0A
CR	Carriage return = 0x0D
U8	Unsigned 1byte integer
U16	Unsigned 2byte integer, Little endian
S16	Signed 2byte integer, Little endian
U32	Unsigned 4byte integer, Little endian
S32	Signed 4byte integer, Little endian
RSV	Empty data of reserved field = 0x00 *Data are sent in multiple of 4 bytes. Therefore, reserved field is used as padding. (4 bytes alignment)

Sensor has two types of internal parameter as below.

Name	Meaning
RO parameter	Read only parameter
RW parameter	Read/Write parameter

1.5 Time stamp

Sensor has an internal counter; its value is known as time stamp. It records the time after the power supply is ON and its unit is millisecond.

Command

There are two types of messages: request commands sent from host to the sensor and response messages sent from sensor to the host. Within the response messages, there are 3 types: Handshake, Continuous and unsolicited responses.

[Basic request command]

C(3) #1	C(n) #2~	LF or CR or CR+LF

#1 Command

#2~ String defined for each command (n=0 is possible)

*While the following explanation applies to all endings, henceforth, LF is used as the request command ending.

*The echo back would include only LF as ending.

[Basic response message]

VSSP Common Header #1~#6
Data defined for every command #7~
…

#1~#6 VSSP Common Header

#7~ Data defined for each command (0 or multiple rows may exist)

[VSSP Common Header format]

‘ V ’	‘ S ’	‘ S ’	‘ P ’	C(3) #1	‘ : ’	C(3) #2	LF
U16 #3		U16 #4		U32 #5		U32 #6	

#1 Packets type

#2 Status (3 Characters)

Type	Number	Meaning
Normal	“ 000 ”	Works well
	“ 021 ”	Internal process overload timeout
	“ 022 ”	Transmission timeout
	“ 099 ”	Initializing…
Request command error	“ 101 ”	Unknown command
	“ 102 ”	Command structure is mismatch
	“ 103 ”	Command parameter is mismatch
	“ 104 ”	Command parameter is out of range
System error	“ 201 ”	System boot failed
	“ 202 ”	System fault

#3 Header bytes count = 24

#4 Response message total bytes count
(The last byte’s position can be inferred from this value)

#5 Time stamp of the request reception

#6 Time stamp of the response

2.1 Response confirmation (PNG command)

[Request command]

‘ P ’	‘ N ’	‘ G ’	LF

#1 Command = “ PNG ”

#2 (No additional string)

[Response message]

VSSP Common Header #1~#6

#1 Packet type = “ PNG ”

#4 Command’s total bytes = 24 (VSSP Common Header only)

2.2 Version information (VER command)

[Request command]

‘ V ’	‘ E ’	‘ R ’	LF

#1 Command = “ VER ”

#2 (No additional string)

[Response message]

VSSP Common Header #1~#6			
C(4) #7	‘ : ’	C(n) #8	LF
…			
C(4) #9	‘ : ’	C(m) #10	LF

#1 Packets type = “ VER ”

#7, #9 …Parameter type

#8, #10 …Parameter response

*This command allows to get multiple information available using GET command at once.

2.3 Parameter acquisition (GET command)

[Request command]

‘ G ’	‘ E ’	‘ T ’	‘ : ’	C(4) #2	LF

#1 Command = “ GET ”

#2 Parameter type (Refer to parameters table next page)

[Response message]

VSSP Common Header #1~#6	
C(n) #7	LF
C(n) #8	LF
C(n) #9	LF
…	

#1 Packets type = “ GET ”

#7 Echo back of the request command
(the ending is converted to LF and appended to # 7)

#8, #9 Parameter’s response (Include 1 or multiple rows of information)

2.4 Parameter setting (SET command)

[Request command]

‘ S ’	‘ E ’	‘ T ’	‘ : ’	C(4) #1	‘ = ’	C(n) #2	LF

#1 Parameter name (Refer to RW parameter of Parameter Table next page)

#2 Parameter value (Refer to RW parameter of Parameter Table next page)

[Response message]

VSSP Common header #1~#6	
C(n) #7	LF

#1 Packet type = “ SET ”

#7 Echo back of the request command
(the ending is converted to LF and appended to #7)

Parameter table

<table>
<tr><th>#2</th><th>Type</th><th>Content</th></tr>
<tr><td>“ vend ”</td><td>RO</td><td>Vendor information</td></tr>
<tr><td>“ prod ”</td><td>RO</td><td>Product information</td></tr>
<tr><td>“ firm ”</td><td>RO</td><td>Firmware version</td></tr>
<tr><td>“ prot ”</td><td>RO</td><td>Protocol version</td></tr>
<tr><td>“ seri ”</td><td>RO</td><td>Serial number</td></tr>
<tr><td>“ tblh ”</td><td>RO</td><td>Table : Horizontal coordinate transform
<table>
<tr><td>Usage</td><td>Used for calculating the horizontal angle of each spot in the line data</td></tr>
<tr><td>Value</td><td>The value position in the 0~65535 interval is relative to the horizontal angle of the corresponding spot in the interval from the first spot and till last spot’s angle.</td></tr>
<tr><td>Data</td><td>Value : Hexadecimal character
Delimiter : ”,” (Comma)
Count : Number of spots in a line</td></tr>
</table></td></tr>
<tr><td>“ tblv ”</td><td>RO</td><td>Table : Vertical coordinate transform
<table>
<tr><td>Usage</td><td>Used for calculating the vertical angle of each spot in the line data</td></tr>
<tr><td>Value</td><td>Value relative to the vertical angle starting from the horizontal 0° and increasing upwards till 360°. it is expressed using 16 bits (Table of absolute angles)</td></tr>
<tr><td>Data</td><td>Value : Hexadecimal character
Delimiter : ”,” (Comma)
Count : Number of spots in a line</td></tr>
</table></td></tr>
<tr><td>“ data ”</td><td>RO</td><td>Data stream state
= The Start/ Stop state of each data streaming.</td></tr>
<tr><td>“ stat ”</td><td>RO</td><td>Data stream status
=a number and an explanation of each data stream’s status.</td></tr>
<tr><td>“ _itl ”</td><td>RW</td><td>Interlaced mode setting. Response each setting by below string
VSSP1.1 Horizontal interlacing number up to 4
VSSP2.0 Horizontal interlacing number up to 20
<table>
<tr><th>State</th><th>Meaning</th></tr>
<tr><td>“ 0,01 ”</td><td>using method no.0 with 1 horizontal /vertical Field</td></tr>
<tr><td>“ 0,02 ”</td><td>using method no.0 with 2 horizontal /vertical Field</td></tr>
<tr><td>“ 0,03 ”</td><td>using method no.0 with 3 horizontal /vertical Field</td></tr>
<tr><td>“ 0,04 ”</td><td>using method no.0 with 4 horizontal /vertical Field</td></tr>
<tr><td>…</td><td>…</td></tr>
<tr><td>“0,20”</td><td>using method no.0 with 20 horizontal /vertical Field</td></tr>
<tr><td colspan="2">While changing _itl, it is recommended to stop data streaming. During data streaming, although can change the _itl parameter and prompt data streaming response. The timing cannot be defined strictly.</td></tr>
</table></td></tr>
</table>

Parameter table 2 (VSSP2.0 New settings)

<table>
<tr><th>#2</th><th>Type</th><th>Content</th></tr>
<tr><td>“_itv”</td><td>RW</td><td>Vertical interlaced mode setting.
<table>
<tr><th>State</th><th>Meaning</th></tr>
<tr><td>“ 0,01 ”</td><td>using method no.0 with 1vertical Field/Frame</td></tr>
<tr><td>“ 0,02 ”</td><td>using method no.0 with 2 vertical Field/Frame</td></tr>
<tr><td>“ 0,03 ”</td><td>using method no.0 with 3 vertical Field/Frame</td></tr>
<tr><td>…</td><td>…</td></tr>
<tr><td>“0,10”</td><td>using method no.0 with 10 vertical Field/Frame</td></tr>
</table>
While changing _itv, it is recommended to stop data streaming. During data streaming, although can change the_itv parameter and prompt data streaming response. The timing cannot be defined strictly.</td></tr>
<tr><td>“_ars”</td><td>RW</td><td>Automatic reset setting
<table>
<tr><th>State</th><th>Meaning</th></tr>
<tr><td>“ 0”</td><td>Disable automatic reset</td></tr>
<tr><td>“ 1 ”</td><td>Enable automatic reset</td></tr>
</table>
In the following case sensor restarts, if automatic reset is enabled.
・Error due to unstable motor rotation
・Resonant mirror error
If excessive vibration and acceleration is added to the sensor, it stops with an error for safety. This function is used to automatically reset from error state to restart the sensor.</td></tr>
<tr><td>“tv00”
“tv01”
“tv02”
…
“tv09”</td><td>RO</td><td>Vertical coordinate transform table during vertical field number is 0 to 9. Format are identical to tblv. The contents of tv00 are identical to tblv. The table number equal or more than the set vertical interlacing number is invalid. Sensor returns error in response to GET command. During each table content acquisition, vertical interlacing number changes according to"_itv".</td></tr>
<tr><td></td><td></td><td></td></tr>
</table>

* Refer to explanation of interlaced mode for the relationship between horizontal field, vertical field and various tables.
* The parameters from th00 to th09 of VSSP 2.0 became unnecessary, therefore the parameters are deleted.

2.5 Data Start / Stop (DAT command)

[Request command]

‘ D ’	‘ A ’	‘ T ’	‘ : ’	C(2) #2	‘ = ’	C(1)#3	LF

#1 Command = “DAT”

#2 Data type

“ ri ”/ “ ro ” = range and intensity / range only

“ ax ” = data of the auxiliary sensors

#3 State

‘ 0 ’ = Stop streaming

‘ 1 ’ = Start streaming

* Starting *ri* or *ro* overwrites each other’s state, the latest would take effect.
* Stopping *ri* or *ro* would stop both of them.

[Response message]

VSSP Common Header #1~#6	
C(n) #7	LF

#1 Packets type = “DAT”

#7 Echo back of the request command
(the ending is converted to LF and appended to #7)

2.6 Error information (ERR response)

[Request command]

When this command is requested, if the sensor is in error state below response is sent to the host.

[Response message]

VSSP Common Header #1~#6	
C(n) #7	LF
C(n) #8	LF
…	
C(n) #9	LF

#1 Packets type = “ ERR ”

#2 Status number ≠ “ 0** ”

#7 Echo back of the request command (the ending is converted to LF and appended to#7.)

#8, #9, Parameter response (Include 0 or multiple rows of information)

2.7 ri format data (_ri response message)

If DAT command is requested with _ri parameter, sensor will start sending distance and intensity continuously.

Usually data of one line fits in one ri response. However, data of one line exceeding the maximum limit of a packet is divided into multiple ri responses.

[Response message]

VSSP Common Header #1~#6
Header of Measurement data
Echo index array
Distance and intensity array

#1 Packets type = " _ri "

#5 Time stamp of the request reception = 0

Distance data header format

U16 #7	U32 #8			U32 #9			S16 #10
S16 #11	U8 #12	U8 #13	U16 #14	U16 #15	U8 #16	U8 #17	U16 #18

#7 Header bytes count = 20 (VSSP1.1 compatible, during vertical interlacing number is1)

Header bytes count =24 (VSSP 2.0 expansion, during vertical interlacing number is 2 or more)

#8 Time stamp of the first spot in the line

#9 Time stamp of the last spot in the line

#10 Horizontal angle the first spot

(Up front 0°, anti-clockwise direction, 360°is expressed in 16 bits)

#11 Horizontal angle of the last spot

(Up front 0°, anti-clockwise direction, 360°is expressed in 16 bits)

#12 Frame Number

#13 Horizontal Field Number (In VSSP1.1 the Field Number)

#14 Line Number

#15 Starting spot's number

(When the data of one line is divided into multiple packets, it will other than 0)

#16 Vertical Field Number

(Appended in case of vertical interlacing number is 2 or more)

#17 Vertical Interlacing Number

(Appended in case of vertical interlacing number is 2 or more)

#18 Reserved (Appended in case of vertical interlacing number is 2 or more)

Echo index array format

U16 #19	U16 #20	U16 #21	U16 #22	…	U16 #23	Rsv *1	Rsv *1

#19 Eco index array bytes count

#20 Spots count

#21, #22 …The position of first echo data in the data array (this array size is expressed in #20)

#23 Spots count

*1 Depending on the number of spots, the reserved field is used as padding to make the array a multiple of 32 bits

Distance and Intensity data format

U16 #24	U16 #25	U16 #26	U16 #27	…

#24, #26 …Distance [mm]
#25, #27 …Intensity
*#23 The total count of the Distance/intensity pair is equivalent to the total echo count

Remark：Data array of ri format

[Data array]
Line no. line = 2
Starting spot no. spot = 5 (※Usually 0)
Echo index array index[] = {0, 2, 3, 4, 6 … }
Distance and Intensity array data[] = {100, 30, 150, 20, 105, 35, 95, 35, 102, 22, 103, 31, 111, 27, … }
User's defined structure array points[]

[Distance and intensity array]
points[0].range_mm = data [0] = line no.2, spot no.5, 1st echo, distance
points[0].intensity = data [1] = line no.2, spot no.5, 1st echo, intensity
points[1].range_mm = data [2] = line no.2, spot no.5, 2nd echo, distance
points[1].intensity = data [3] = line no.2, spot no.5, 2nd echo, intensity
points[2].range_mm = data [4] = line no.2, spot no.6, 1st echo, distance
points[2].intensity = data [5] = line no.2, spot no.6, 1st echo, intensity
points[3].range_mm = data [6] = line no.2, spot no.7, 1st echo, distance
points[3].intensity = data [7] = line no.2, spot no.7, 1st echo, intensity
points[4].range_mm = data [8] = line no.2, spot no.8, 1st echo, distance
points[4].intensity = data [9] = line no.2, spot no.8, 1st echo, intensity
points[5].range_mm = data [10] =line no.2, spot no.8, 2nd echo, distance
points[5].intensity = data [11] =line no.2, spot no.8, 2nd echo, intensity
points[6].range_mm = data [12] =line no.2, spot no.9, 1st echo, distance
points[6].intensity = data [13] = line no.2, spot no.9, 1st echo, intensity

[Spot data acquisition procedure]
Echo count of the spot i= index[i + 1] - index[i]

To access all echo data of specified spot

```
For (p = index [ i ], echo=0; p <= index[ i + 1 ]; ++p, ++echo){
        // Here points[] processing goes
        // Echo no. 0=1st echo, 1=2nd echo

}
```

Caution

i is in the interval from 0 to #20 (Spots count) - 1.
Index [#20] =#23.Therefore, using the index array echoes of each spot could be determined.

2.8 ro format data (_ro response message)

If DAT command is requested with _ro parameter, sensor will starts sending only distance continuously.

Usually data of one line fits in one ri response. However, data of one line exceeding the maximum limit of a packet is divided into multiple ri responses.

[Response message]

VSSP Common Header #1~#6
Header of Measurement data
Echo index array
Measurement data array

#1 Packets type = " _ro "
#5 Time stamp of the request reception = 0

Measurement data header format

U16 #7	U32 #8			U32 #9			S16 #10
S16 #11	U8 #12	U8 #13	U16 #14	U16 #15	U8 #16	U8 #17	U16 #18

#7 Header bytes count = 20 (VSSP1.1 compatible, during vertical interlacing number is 1)
Header bytes count =24 (VSSP 2.0 expansion, during vertical interlacing number is 2 or more)
#8 Time stamp of the first spot in the line
#9 Time stamp of the last spot in the line
#10 Horizontal angle the first spot
(Up front 0°, anti-clockwise direction, 360°is expressed in 16 bits)
#11 Horizontal angle of the last spot
(Up front 0°, anti-clockwise direction, 360°is expressed in 16 bits)
#12 Frame Number
#13 Horizontal Field Number (In VSSP1.1 the Field Number)
#14 Line Number
#15 Starting spot's number
(When the data of one line is divided into multiple packets, it will other than 0)
#16 Vertical Field Number
(Appended in case of vertical interlacing number is 2 or more)
#17 Vertical Interlacing Number
(Appended in case of vertical interlacing number is 2 or more)
#18 Reserved (Appended in case of vertical interlacing number is 2 or more)

Echo index array format

U16 #19	U16 #20	U16 #21	U16 #22	…	U16 #23	Rsv*1	Rsv*1

#19 Eco index array bytes count
#20 Spots count
#21, #22 …The position of first echo data in the data array (this array size is expressed in #20)
#23 Total echoes count
*1 Depending on the number of spots, the reserved field is used as padding to make the array a multiple of 32 bits

Measurement data array format

U16 #24	U16 #25	U16 #26	U16 #27	…

#24, #25, #26, #27 …Distance [mm]

*#23 The total count of Distance is equivalent to the total echo count

Explanation : Data array of ro format

[Data array]
Line no. line = 2
Starting spot no. spot = 5 (*Usually 0)
Echo Index array index[] = {0, 2, 3, 4, 6 … }
Measurement data array data[] = {100, 150, 105, 95, 102, 103, 111, … }
User's defined structure array points[]

[Measurement data array]
points[0]. range_mm = data [0] = line no.2, spot no.5, 1st echo, distance
points[1]. range_mm = data [1] = line no.2, spot no.5, 2nd echo, distance
points[2]. range_mm = data [2] = line no.2, spot no.6, 1st echo, distance
points[3]. range_mm = data [3] = line no.2, spot no.7, 1st echo, distance
points[4]. range_mm = data [4] = line no.2, spot no.8, 1st echo, distance
points[5]. range_mm = data [5] = line no.2, spot no.8, 2nd echo, distance
points[6]. range_mm = data [6] = line no.2, spot no.9, 1st echo, distance

[Spot data acquisition procedure]
Echo count of the spot i= index[i + 1] - index[i]

To access all echo data of specified spot

```
For (p = index [ i ], echo=0; p <= index[ i + 1 ]; ++p, ++echo){
    // Here points[] processing goes
    // Echo no. 0=1st echo, 1=2nd echo

}
```

Caution
i is in the interval from 0 to #20 (Spots count) - 1.
Index [#20] =#23.Therefore, using the index array echoes of each spot could be determined.

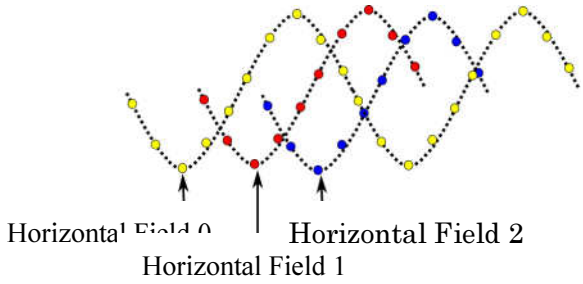
Explanation : About Interlaced Mode

While maintaining the direction of each laser spot constant by synchronizing scanner and mirror, sensor can change spot direction with interlacing mechanism.

In addition to horizontal interlacing defined in VSSP 1.1, vertical interlacing have been introduced in VSSP 2.0 and 2.1.

When horizontal and vertical interlacing number is specified to 1 sensor does not use interlacing. If the interlacing number is specified 2 or more, the spot direction will change.

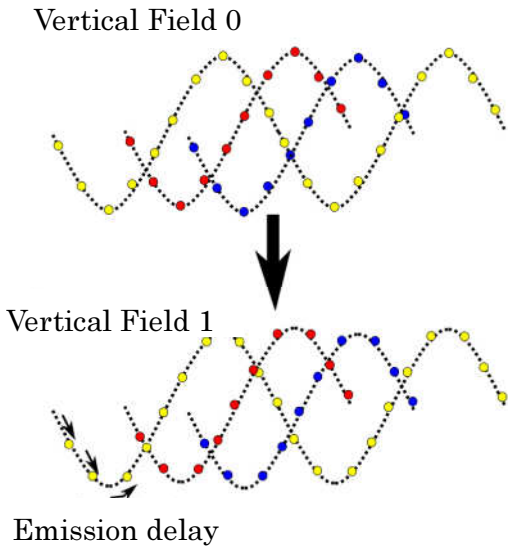
Let N be the horizontal interlacing number. Horizontal interlacing is performed by increasing rotation time period with N-th fraction of vertical interlacing time period. The interlaced spot path shifts in each rotation and will return to the same path after N-th rotation. The laser spots in each rotation is called “field” which is assigned with horizontal field number from 0 to (N-1). The figure below shows spot path when horizontal interlacing number is 3.



Vertical interlacing is performed by delaying the laser emission timing. Changes of spot direction is not only vertical, but also horizontal (along the spot curve path). The emission delay time remains constant during one horizontal interlacing cycle and changes at the start of horizontal field 0. Let M be the vertical interlacing number. The vertical interlacing is performed by delaying spot emission time from the original timing with multiple of M-th fraction of spot interval time period. This discrete delay time is assigned the number from 0 to (M-1) which is called vertical field number. The schematic diagram below shows, spot position changes, when horizontal interlacing number is 3 and vertical interlacing number is 2. Spot emission delay time returns to original position after a cycle (delay time identical to original spot). Also, vertical field number returns to 0.

Delayed spot positions of particular vertical field number differs according to vertical interlacing number. Therefore, table tv00 to tv09 changes according to the value of parameter _itv. During vertical interlacing number is M, the valid table number is up to N-1. The sensor returns error in response to GET command of invalid tables. In VSSP 2.1 many tables are introduced, therefore users should acquire all the table data before measurement operation.

When performing vertical interlacing, not only spot position changes in vertical angle but also changes in horizontal angle along the spot path. The line start and end position in distance measurement of header includes changes in horizontal angle, then the reference table for horizontal angle is only tblh which does not change according to the vertical interlacing number.



In below table, vertical interlaced mode setting "_itv" value and acquisition possible table.

Vertical interlacing number with valid table

Vertical interlaced mode setting "_itv" (Vertical interlacing number)	Valid table
"0,01"	tv00
"0,02"	tv00, tv01
"0,03"	tv00, tv01,tv02
…	…
"0,10"	tv00, tv01,tv02,…,tv09

2.9 ax format data (_ax response message)

If DAT command is requested with _ax parameter, sensor will start sending auxiliary sensor's data including gyro continuously.

[Response message]

VSSP Common Header #1~#6
Auxiliary Data Header
Auxiliary Data

#1 Packets type = " _ax "

#5 Time stamp of the request reception = 0

Auxiliary data header format

U16 #7	U32 #8	U32 #9	U8 #10	U8 #11

#7 Header bytes count = 12

#8 Time stamp of the first data

#9 Bit field of measurement data type

Bit	Content	bit	Content
32	Angular speed X axis	16	Undefined
31	Angular speed Y axis	15	Undefined
30	Angular speed Z axis	14	Undefined
29	Acceleration X axis	13	Undefined
28	Acceleration Y axis	12	Undefined
27	Acceleration Z axis	11	Undefined
26	Magnetic X axis	10	Undefined
25	Magnetic Y axis	9	Undefined
24	Magnetic Z axis	8	Undefined
23	Temperature	7	Undefined
22	Undefined	6	Undefined
21	Undefined	5	Undefined
20	Undefined	4	Undefined
19	Undefined	3	Undefined
18	Undefined	2	Undefined
17	Undefined	1	Undefined

* Each axis data's direction, unit and valid range are mentioned in the sensor's manual.

* The content of the packet is described by the bit field. The refresh rate of each auxiliary sensor is different. Therefore, packets with different content is sent.

#10 Data count (varies depending on the availability of the data).

#11 Time interval of between data reading [ms]

Auxiliary data format

S32 #12	…

#12,…Sequence of the data as described by the bit field

*#9 Measurements are lined up in the same order of "1" in the bit field starting from the most significant bit (MSB)

* Sets described by the bit fields are lined up #10 times.

2.10 er format data (_er response message)

In case of error, sensor sends this unsolicited response message.

[Response message]

VSSP Common Header #1~#6	
C(n) #7	LF
C(n) #8	LF
…	

#1 Packets type = " _er "
#2 Status number = "2**"
#7, #8,…Parameter response (Includes 0 or multiple rows of information)

[Caution]

- All data streaming are stopped and the sensor stops working.
- User should check and restart the sensor.

2.11 Restart (RST Command)

VSSP 2.0 new command

【Request command】

'R'	'S'	'T'	LF

#1 Command = "RST"
#2 (No additional string)

【Response message】

VSSP Common Header #1~#6

#1 Packet type = " RST "
#4 Command's total bytes = 24 (VSSP Common Header only)

When sensor receives RST command, sensor restarts. This command has similar effect of sensor restart as the power re-supplied.

Reference

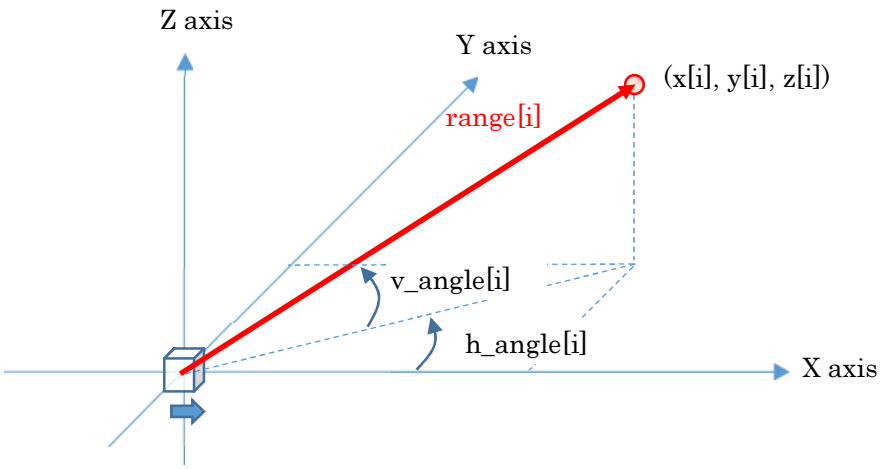
3D Coordinate transformation

As shown below, using coordinate transformation, a measurement point can be converted to its 3D counterpart.
X, Y, Z axis directions are respectively front, left and upper direction as in the right-hand rule. Horizontal angle and vertical angle starts from the X axis and rotates in anti-clockwise direction and upper direction respectively. Length unit is expressed in meter (m) and millimeter (mm). Angle unit is expressed in radian (2π).
i = Spot number
v_angle[i] = tblv[i] * 2π / 65535
h_angle[i] = (line_head_h_angle_ratio + (line_tail_h_angle_ratio - line_head_h_angle_ratio) * tblh[i] / 65535) * 2π / 65535

※tblh and tblv arrays are received using GET command. The first and last spot's horizontal angle differ among measurements. Therefore, it is necessary to calculate h_angle[i] after the reception of each line.

Transformation from Polar coordinate to Cartesian coordinate is performed using the following calculation.
x[i] = range[i] * cos(v_angle[i]) * cos(h_angle[i])
y[i] = range[i] * cos(v_angle[i]) * sin(h_angle[i])
z[i] = range[i] * sin(v_angle[i])

To calculate the spots horizontal from the absolute angle of the spot of the beginning and the end for horizontal measurement range varies by line



Data range

Line's count in one field may differ depending on the measurement circumstance. The received field's data may exceed the specified sensor's horizontal field of view.

State transition diagram

State transition of the sensor with VSSP specification is shown below