BEAM

Blacknest Data System (BDS)

Instrument Response handling – 2.2.6 – 2021-03-29

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1. Introduction

The BDS system stores channels of time sampled data from a number of measurement instrument types. As well as the normal earth movement seismic sensors there are also pressure, hydrophone and other sensor data.

This data is stored as a set of time domain numerical values on a per channel basis in sensor data files. For each channel there is Metadata, stored in a database, to describe the scaling and frequency response of these of these data sets to provide data values in the measured quantities SI units.

The BDS system stores, manages and retrieves instrument responses from its internal database. This document briefly describes this process and the external formats supported.

2. Calibration Data

The fundamental channel scaling Metadata is held in the Calibration database table There are three parameters for each channel stored that provide the overall scaling and SI units of the data. These are:

Type	***Name***	***Description***
Float64	samplingFrequency	The sample rate used in Hz
Float64	calibrationFrequency	The frequency that the CalibrationFactor value is valid for.
Float64	calibrationFactor	The scaling value to apply to the data to normalise data to the units. This is a measured value at the calibration frequency.
String	calibrationUnits	The measurement SI units such as “m”. These units should be the primary units such as “m” not “nm”. Current core units are: m, m/s, m/s^2, s, Pa, K. degrees (for wind direction sensors), V, A (for hydroacoustic state-of-health sensors)

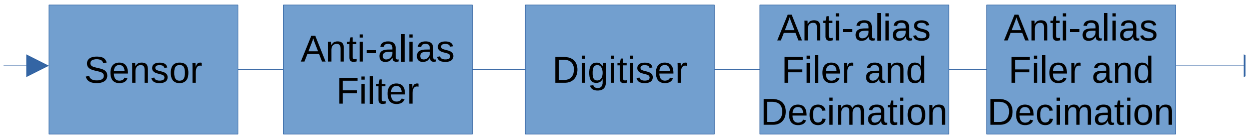
3. Frequency Response Information

As well as the basic scaling information, for each channel there can be a set amplitude/phase frequency response information. Most seismic sensor channels have this information.

The frequency response information is normally provided either as a single overall response or as a set of individual processing stage frequency response data. There can be a frequency response for the sensor, the analogue anti-aliasing filter, the digitiser with digital anti-aliasing filter and digital decimation filter stages etc. Channels vary in the type of responses and number of stages of frequency responses provided. To obtain the most accurate overall frequency response the user should calculate the combined effect of all of the stage responses, although typically it is the stage 1 sensors frequency response that is dominant.

An exception is for certain infrasound sensors in the IMS network, e.g. I52, for which the first stage of the response is not the pressure sensor but the wind-noise reduction system, represented as a FAP table, and the pressure sensor response is shown as the second stage.

It is expected that imported multiple stage sets have the core instrument response as stage 1 and is named “instrument” as per the standard IDC naming scheme. following this can be any number of named stages. Typically these will be named “digitizer”. The BDS uses the internal response stage 0 named “Overall” as its primary overall response. When importing just a single response for a channel this is stored as stage 0 and named “Overall”. If a set of multiple stage responses are imported, these are imported as is (1, 2, 3) and a stage 0 named “Overall” entry is added based on the stage 1 “instrument” one imported.


Sensor
Anti-alias Filter
Digitiser
Anti-alias Filer and Decimation
Anti-alias Filer and Decimation

The frequency response of each stage is defined by one of: a set of poles and zeros, a set of FIR coefficients or a FAP (frequency, amplitude, phase) table.

Individual stages are defined by number starting at stage 1 which will be the response of the sensor itself and will normally be of a PoleZero form. For each stage the BDS stores or calculates the following core information:

Name	***Type***	***Description***
stage	Integer	The stage number of the response. 0 is for overall response, 1, 2, 3 … for the individual stages.
name	String	The responses name (Overall, instrument, digitiser, anti-aliasing filter, post filter, wind-noise reduction system (WNRS), etc)
type	String	The type of response (PoleZero, FAP or FIR)
data	Blob	PoleZero, FAP or FIR Coefficient data. This is stored in an encoded HEX/ASCII format. We could store as a more readable ASCII)
gain	Double	Overall gain at gain frequency. This is either calculated from the response data if this value is 0 or provided here.
gainFrequency	Double	Frequency that gain is valid for. If 0 assumes the overall channel’s calibrationFrequency
decimation	Double	Decimation performed post filter. if 0 unknown. Can be calculated if samplerate is given for all stages.
sampleRate	Double	The stage's sample rate if set. generally for Digitiser FIR filters. Set to 0.00 for analogue or unknown. Can be calculated if decimation value is given for all stages.

Most of the legacy Metadata imported into the BDS does not have the full information for these fields. In the case of numerical fields a value of 0 means undefined.
Some export formats, such as StationXml requires the gain, gainFrequency, decimation and sampleRate information for each stage. If this information is not present the BDS will attempt to calculate it. It will perform the following:

- Set the gainFrequency to the calibrationFrequency.
- Calculate the stages amplitude gain at the calibrationFrequency and set the gain field accordingly.
- Work back from the final samplingFrequency setting the stages decimation and sampleRate accordingly. If neither decimation or sampleRate is know for a stage assume a decimation of 1.
- Work back from the final calibrationUnits setting the stages output units accordingly.

We could store the calculated values back into the Response database to save re-calculating these each time. But then we would not know if these were calculated or provided values.

3.1. Response Stages

- **Stage 0:** If stored this will be an overall channels frequency response and is an internal BDS construct. When exporting data this will be provided as stage 1 if there are no other stages present. Often in pole-zero or FAP form would be named "Overall".
- **Stage 1:** This will normally be the sensors response and is often given in pole-zero form and named "instrument". For IMS infrasound sensors Stage 1 might be the wind-noise reduction system, named "wnrs" and represented as a FAP table, in which caee the sensor is stage 2 and subsequent stage numbers are increased by one.
- **Stage 2:** This may be the analogue anti-aliasing filters response. Often will be provided in pole-zero form. Would be named "instrument" in this case.
- **Stage 2 and up:** This will normally be the frequency responses of the digitiser and following digital anti-aliasing filters and decimation stages. Often will be provided in Finite-Impulse-Response (FIR) filter form and named "digitizer"

4. Response Internal Storage

The BDS stores responses in the Responses table of its internal Mysql database. The following information is stored:

Name	***Type***	***Description***
id	Integer	Unique ID for this entry
startTime	String	The Start time
endTime	String	The End time
network	String	The Network name
station	String	The Station/Array name
channel	String	The Channels primary identifier
source	String	The Source of the data this metadata is for
stage	Integer	The stage number of the response. 0 is for Overall response
name	String	The responses name (Overall,instrument,digitiser,anti-aliasing filter, post filter etc)
type	String	The type of response (PoleZero, FAP or FIR)
data	Blob	PoleZero, FAP or FIR Coefficient data. This is stored in an encoded HEX/ASCII format.
gain	Double	Overall gain at gain frequency. (For information)
gainFrequency	Double	Frequency that gain is valid for. (For information)
stageType	String	The stage type: A - Analog (rad/sec), B - Analog (Hz), C - Composite, D - Digital

decimation	Double	Decimation performed post filter.
symmetry	String	Symmetry for FIR coefficients (A = asymmetric, B = symmetric[odd], C = symmetric[even]). (For information)
description	String	General description
measured	Boolean	Set if response was a measured response.
sampleRate	Double	The stage's sample rate if set. generally for Digitiser FIR filters. set to 0.00 if not used.
lastUpdate	Timestamp	DateTime this record was last updated

Each BDS channel can have multiple responses stored. There can be multiple responses due to changes based on time (such as Sensor or Digitiser changes) and due to the different stages in the Sensor and Digitiser processing pipelines.

The network:stations:channel:source fields are used to link the response to a particular BDS channel. The startTime and endTime fields are used for time related response changes. The multiple processing stages are defined using the stage and name fields.

The type field defines the type of response. At the moment PoleZero, FAP and FIR types are supported. The actual response data is stored in the data blob using the BOAP data serialising scheme.

4.1. Response Types

The BDS supports the following response types:

- **PoleZero:** This consists of a set of poles and a set of zeros each represented as complex numbers~~.~~ The units are assumed to be radians/second [or: the units are radians/second or Hz as denoted by the “poleZeroUnits” variable.][or whatever it is called in the end].
- **FAP:** This consists of a set of frequency, amplitude and phase values. The amplitudes are expected to be dimensionless.
- **FIR:** This consists of a set of “b” (numerator) coefficients and a set of “a” denominator coefficients with an error value for each.

5. Response Export

There didn’t used to be any well named and documented response file formats although more recently the SEED metadata and StationXML formats have become more dominant. The BDS supports the following external representations of responses:

Type	*Description*
STATIONXML	New standard format for a Stations channel’s response metadata.
SEED-METADATA SEED	SEED files supported for export of responses and sensor data with response metadata
IMS-RESPONSE IMS-POLEZERO IMS-FAP IMS	IMS files supported for export. The responses of other systems that do not conform to the IMS standard are converted as necessary, including integration of velocity or acceleration responses to displacement. The units of the stored response are taken from the “calibrationUnits” value in the “Calibrations” table.

Type	*Description*
RESPONSE	Generic for import of any of the supported formats. Scans the file to determine the format.
RESPONSE-SAC-POLEZERO	This is a simple ASCII format for PoleZero response import and export. It looks like: ZEROS 5 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 -3030.0000 0.0000 POLES 4 -0.3950 0.0000 -3.8330 4.9790 -3.8330 -4.9790 -42.6800 0.0000 CONSTANT 360.992094 (the “CONSTANT”, or normalisation factor, is NOT multiplied by the calibration factor)
RESPONSE-RAW-FAP	This is a simple ASCII format for FAP response import and export. It looks like: 5.000000E-02 9.651473E+08 1.303462E+01 6.147467E-02 9.735240E+08 1.026658E+01 7.558270E-02 9.790335E+08 7.895283E+00 9.292844E-02 9.824989E+08 5.838499E+00 1.142549E-01 9.844650E+08 4.018842E+00 1.404756E-01 9.852573E+08 2.364227E+00 1.727139E-01 9.850285E+08 8.069217E-01 2.123506E-01 9.837949E+08 -7.181713E-01 2.610836E-01 9.814743E+08 -2.275690E+00 The amplitudes are dimensionless multiplication factors.

Type	*Description*
RESPONSE-IDC	Generic IDC ASCII response for import/export. this is of the form: theoretical 2 instrument paz description 1.40568e+12 3 -9904.8 3786 0 0 -9904.8 -3786 0 0 -12507 0 0 0 0 theoretical 4 digitizer fir 30000 5 3.788775e-05 0 1.997269e-04 0 5.912768e-04 0 1.198337e-03 0 1.677196e-03 0
RESPONSE-IDC-POLEZERO RESPONSE-IDC-FAP	These are the specific PoleZero and FAP formats for export choice. If response is stored in PoleZero format will be converted and exported as FAP if RESPONSE-IDC-FAP is chosen. These will only export the first overall instrument response (stage 0, “Overall”). When used for import, only the first response in a multi-stage file will be imported (or the second if the first is a wind-noise reduction system on an infrasound channel).

5.1. Responses Export Programs

The bdsAdminGui, bdsuserGui, bdsDataAccess and bdsMetadata programs all support the export of responses. The user supplied format defines the export format. Responses can be exported on their own or with the data in certain formats such as SEED and IMS. When the IMS format is selected, the response is converted into a displacement response for seismic sensors (including the mass position sensors used in instrument state-of-health monitoring), or pressure for infrasonic or hydroacoustic sensors. For other export formats the response is exported in the units in which it is stored, which for seismic sensors might be velocity or acceleration. The units are given in the appropriate slots in the output format.

There may need to be a flag to export all of the response stages rather than just the primary stage 0 “Overall” response.

6. Import of Responses

The bdsAdminGui, bdsuserGui and bdsMetadata programs all support the import of responses from the various ASCII response files. There is no program to import from SEED or StationXML files as yet. In the future a new bdsImportResponse will be created.

The bdsImportResponse module imports responses in the following formats: IMS from file headers (CAL2, PAZ2, FAP2 and FIR2 entries), IMS from “static” database and corresponding response-file directory, SEED, StationXML. It does not translate responses between domains, e.g. a response in velocity units is stored as such rather than converted to displacement, but it does convert non-SI units specified in the file or by the relevant standard into SI, e.g. Pa or m or m/s, and station elevations and depths into m. The following inconsistencies and errors in the input response are flagged but not corrected:

- Poles with positive real parts accompanied by a positive “constant” (normalisation factor), giving rise to an acausal response;

- A normalisation factor not equal to the one calculated from the given poles-and-zeros (only order-of-magnitude differences are flagged because smaller differences might arise from accumulated floating-point precision errors in the ratio of polynomials where there are large numbers of poles or zeros);

- Inconsistent normalisation frequencies (or periods) where these are specified for more than one stage of a multi-stage response;

- Units specified as velocity (m/s or nm/s) where there are not at least two zeros at (0,0), and units specified as displacement where there are not at least three zeros at (0,0);

- Necessary units not specified. In this case the response will be imported “as is”. Poles-and-zeros will be assumed to be in radians/s if the units are not specified, but other units will need to be inserted by the user before the metadata, or data using these metadata, can be exported.

If the input response file or source has irresolvable inconsistencies with the standard for that format, import will fail.

7. Further Information

For further information please look at the BDS system documentation at: https://portal.beam.ltd.uk/support/blacknest.