LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY
-LIGO-
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Technical Note **LIGO-T060064- 00- E** 3/23/2006

Provenance of Detector Geometry Values in LIGO Frame Files

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This is an internal working note
of the LIGO Project.

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ABSTRACT

The raw frame files written by the LIGO frame builders contain static detector geometry information in FrDetector structures. This technical note explains the origins of the numerical values stored in those structures, and their evolution over the first few science runs.

INTRODUCTION

Version 6 of the frame format specification was finalized in August 2002; see the document "Specification of a Common Data Frame Format for Interferometric Gravitational Wave Detectors (IGWD)", LIGO-T970130-F-E. This version featured several changes to the FrDectector structure used to store detector geometry information, including changing angle values from (degrees,minutes,seconds) to decimal radians and adding the half-lengths ("midpoints") and altitudes of the arms. As described below, there were some problems implementing this change for LIGO frame files written during the S2 run. These problems were fixed prior to the S3 run.

The detector geometry values contained in a frame file can be interrogated in at least two ways:

- Using the FrDump program, which is part of the Virgo FrameLib, with a debug level of 4 (or greater). For example: `FrDump -i L-R-792866800-16.gwf -d 4`

- Using the FrGeomDump program in the LIGOtools "FrContrib" package

The primary reference for interferometer locations and arm orientations is this article: W. E. Althouse, S. D. Hand, L. K. Jones, A. Lazzarini, and R. Weiss, "Precision alignment of the LIGO 4 km arms using the dual-frequency differential global positioning system", Review of Scientific Instruments **72**, 3086 (2001). This article has the DCC number LIGO-P000006-D-E. To complete the interferometer geometry information, arm cavity half-length values were taken from detector e-log entries, as described below.

FRAME FILES WRITTEN DURING THE S2 SCIENCE RUN

The LIGO frame builders were upgraded to write version 6 frames before the S2 science run (Feb.-April 2003). However, the detector geometry information was not properly converted from the version 4 conventions to the version 6 conventions at that time, and so the frame files written during the S2 science run have incorrect detector geometry information. The situation is summarized in an email message from July 24, 2003:

```
Subject:  Re: Geometry data
From:  Peter Shawhan <shawhan_p@ligo.caltech.edu>
Date:  7/24/2003 3:09 PM PDT
To:  John T. Whelan <jtwhelan@loyno.edu>
Cc:  LAL-discuss Mailing List <lal-discuss@gravity.phys.uwm.edu>, Benoit
Mours <mours@lapp.IN2P3.fr>, Philip Charlton <charlton@ligo.caltech.edu>,
Szabi Marka <smarka@ligo.caltech.edu>

Hi John and others,

OK, here's the full story:

1. The S1 raw frames contain the correct geometry information (they are
version-4 frames, and the stored values follow the version-4 conventions).
The frameCPP library used by LDAS reads this info and correctly converts
it to the version-6 conventions, so that is what an LDAS job would receive.
```

The VIRGO FrameLib converts latitude and longitude to decimal radians, but it does so erroneously for east longitudes; also, it does not convert the arm azimuth angles from the version-4 convention (CCW from east) to the version-6 convention (CW from north). So the incorrect values displayed by the FrDump utility for S1 raw frames are a problem with the software, not with the frames themselves.

2. The S1 RDS frames contain the correct geometry information, following the version 5/6 conventions, except that the azimuth angles are negative whereas the spec says they should be in the range 0 to 2pi. They just differ by 2pi, so this should not be a problem. frameCPP and FrameLib read the geometry values correctly, and FrDump displays them correctly.

3. The S2 raw frames contain incorrect geometry information, as I described yesterday, due to insufficient quality control when the CDS frame builder was switched from writing version-4 frames to writing version-6 frames. These are version-6 frames, so frameCPP, FrameLib, and FrDump read and display these (incorrect) values without modifications.

4. The S2 RDS frames are like the S2 raw frames.

5. The S2 NDAS frames are an interesting case. The original LIGO frames were produced by the CDS frame broadcaster, which, as far as I can tell, was still producing version-4 frames with correct geometry information, even though the CDS framebuilder which wrote the raw files to disk had been switched to version 6 frames. So the NDAS frame-merging program received correct LIGO geometry information, but it is based on FrameLib, and due to the behavior of FrameLib as described in item 1, the geometry information was not properly converted to the version-6 conventions before the merged frame was written out (as a version-6 frame). So the NDAS frames contain incorrect geometry information, as you observed.

I will send Benoit a list of corrections for FrameLib, and will make sure the CDS folks have the correct geometry information for frames to be written in the future. As for the S2 data which was written with incorrect geometry information, it's not clear how to proceed. If all analysis groups have alternative mechanisms to specify the detector geometry, perhaps the incorrect values in the frames can just be ignored? It would be technically feasible to add a hack to frameCPP, at least, to fix the geometry information as the data is read, but Kent was unenthusiastic about this idea.

Peter

The details about what is wrong with the geometry information in the S2 raw frames are described in this excerpt from an email message from the previous day:

Subject: Re: [LAL-Discuss] Incorrect geometry data for LLO (azimuth in E7, longitude still)
From: Peter Shawhan <shawhan_p@ligo.caltech.edu>
Date: 7/23/2003 6:02 PM PDT
To: LAL-discuss Mailing List <lal-discuss@gravity.phys.uwm.edu>
Cc: Benoit Mours <mours@lapp.IN2P3.fr>, Philip Charlton <charlton@ligo.caltech.edu>, Szabi Marka <smarka@ligo.caltech.edu>

...
HOWEVER, here's what we have in the S2 frames (which are version-6 frames):

Livingston:
longitude is 30.5628943337 radians east of Greenwich
latitude is -90.7742403889 radians north of equator
elevation is -6.57399988174 meters above WGS84 ellipsoid
armXazimuth is 3.45080399513 radians clockwise from north
armYazimuth is 5.02159976959 radians clockwise from north

Hanford:
longitude is 46.455146655 radians east of Greenwich
latitude is -119.40765642 radians north of equator
elevation is 142.554000854 meters above WGS84 ellipsoid

```
armXazimuth is 2.19910407066 radians clockwise from north
armYazimuth is 3.76990103722 radians clockwise from north

These values are very wrong!  The text after the values above is what
the values are SUPPOSED to mean, according to the version-6 frame spec.
The longitude and latitude values are swapped, and are expressed in
degrees rather than radians, while the azimuth values are given as
radians counter-clockwise from east rather than radians clockwise from
north.  So, it seems that when the CDS framebuilder was switched over
to making version-6 frames, there was a breakdown of communication
about making sure the correct values were put into the revised geometry
structure.

...
```

Finally, the S2 Hanford frame files (as well as the Livingston frame files) contain a single FrDetector structure with arm midpoint values of zero.

FRAME FILES WRITTEN DURING THE S3 THROUGH S5 RUNS

The interferometer location and orientation information was fixed in July 2003. In September 2003, we changed the Hanford frame files to contain two FrDetector structures, differing only in the arm midpoint values. The arm midpoint values for all three interferometers were set according to whatever Peter could find in the e-logs about arm lengths at the time. Precise arm lengths for H1 (X=3995.08418 m ± 0.08 mm, Y=3995.04437 m ± 0.08 mm) were reported by Rick Savage and Malik Rakhmanov in
http://blue.ligo-wa.caltech.edu/ilog/pub/ilog.cgi?group=detector&date_to_view=05/30/2003&anchor_to_scroll_to=2003:05:30:12:29:44-rick .
For L1, Peter found a single number for the arm length, 3995.15 m, cited by Rana in
http://www.ligo-la.caltech.edu/ilog/pub/ilog.cgi?group=detector&date_to_view=05/29/2003&anchor_to_scroll_to=2003:05:29:20:23:07-rana
and took that to be the same for both arms.
For H2, Peter could only find an old, rough number for the arm length, 2009 m, in
http://blue.ligo-wa.caltech.edu/ilog/pub/ilog.cgi?group=detector&date_to_view=02/18/2000&anchor_to_scroll_to=2000:02:20:10:40:16-stan .
"Midpoint" values, equal to half of these arm lengths, are contained in the frame files written in the S3 through S5 science runs. Despite the disparity in accuracies, these length values in the frame files should be good enough (if they are used at all) since all of the lengths are accurate to a small fraction of a percent. Therefore, it is likely that the same values will continue to be used in science runs after S5 as well, even if better arm length measurements are available.