A first release of $\nu$Solve

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Introduction
The new VLBI data analysis software
Plans for future

New generation VLBI data analysis software
- Increase in number of observations.
- VLBI2010 introduce new observables.

History of development
- The IVS Working Group on VLBI data structures (IVS WG4) was established in 2007.
- In August of 2009 the VLBI group at the NASA GSFC started the development of new VLBI data analysis software.
- A design of system architecture was presented at the IVS General Meeting at Hobart (Tasmania) in 2010.
- We demonstrated a prototype version of $\nu$Solve at the 20$^{th}$ EVGA Meeting in Bonn, 2011.

$\nu$Solve and VLBI data flow
- $\nu$Solve is designed to replace most sensitive and user time consuming part of CALC/SOLVE system, interactive SOLVE.
- It produces Version 4 databases: edited, ambiguity resolved and with ionospheric corrections.

In this presentation we will cover the current status of the software development process.
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Geodetic VLBI data flow

Correlator output → dbedit → Ver 1 Database

Ver 1 Database → calc → Ver 2 Database

Ver 2 Database → dbcal → Ver 3 Database

Ver 3 Database → interactive solve → Ver 4 Database

Ver 4 Database → mksup → Superfiles

Superfiles → global → Solution

ν Solve → OpenDB

ν/mksup ?
The software is designed to (but not limited) work under Linux/GNU operation system.

It is written in **C++ programing language**.

We distribute the software code and use **GNU Build System** to make it portable.

It uses the **Qt** library for high level data abstraction and system **libc, libm** for low level system functions.

Currently, it consists of two parts:

- **Space Geodesy Library**, where all algorithms are implemented (90% of source code);
- an executable **νSolve** – a driver that calls the library and organizes work with an end-user (10% of source code).
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Plans for future

Structure of the Software

Functionality

Modular structure of the software

To keep our system stable and flexible we designed it modular.

**Module** is a logical block of code that is loosely tied with other parts of the software.

Each arrow on the diagram represents a **dependency** or, in other words, provides information (types, function calls, constants).

Only main **dependencies** are shown on the diagram.


A first release of νSolver

5 / 17
General features

Current functionality

The software is able:

- Read/Write files in Mk3 DBH format;
- Display various information that were stored in the files;
- Process a single VLBI session and save results;
- Estimate various parameters;
- Detect and process clock breaks;
- Resolve ambiguity;
- Perform ionospheric correction;
- Calibrate weights of observations;
- Eliminate outliers;
The new VLBI data analysis software

Plans for future

Structure of the Software
Functionality

General features

Current functionality

The software is able:

- The software is able to read and write data in Mk3 DBH format.
- It can also use new OpenDB format.
- There is no limitations on number of stations, sources or observations.
- It can work either through CALC/SOLVE catalog subsystem or in a standalone mode.
- Process of VLBI data analysis can be automated,
General features

Data processing

- **Single session mode:**
  - νSolve is designed to analyze a single session, performs necessary calibrations and data editing.
  - Later it will evolve in powerful session editor that allows us to fix all known anomalies of the VLBI observation.

- **Multiple session mode:**
  - A separate executable (driver) will be developed to perform data analysis of multiple sessions of VLBI observations.
Estimated parameters

We can estimate:

- Clock parameters;
- Zenith delays and their gradients;
- Stations positions;
- Sources coordinates;
- Polar motion;
- Earth rotation and its rate;
- Angles of nutation.

![Parameters to estimate]

- Clocks model:
- Zenith delays:
- Atmospheric gradients:
- Station Coordinates:
- Source Coordinates:
- Polar motion:
- Earth rotation (dUT1):
- Change of Earth rotation (dUT1 rate):
- Nutation angles:

Estimated parameters
The estimated parameters can be modeled as:

- Local parameter – an unbiased parameter determined for whole session
- Arc parameter – an unbiased parameter estimated for specified by user interval (e.g., 1 hour)
- Piecewise linear function, coefficients of continuous linear function are estimated from data, an interval between nodes is specified by user
- Stochastic parameters

There is no limitations on length of arcs or step between nodes of piecewise linear functions.
Clock break correction

Clock break processing

- To compensate a clock break, $\nu$Solve adds a step-wise linear function to the station clocks.
- There are session wide and band dependent clock break models.
- Clock breaks can be detected and corrected in automatic, semi-automatic and manual mode.

Example of a 1 second clock break
Ambiguities

**Ambiguity resolution**

- Ambiguity resolution is done using ideas implemented in CALC/SOLVE.
- There is no assumption about ambiguity spacing. $\nu$Solve can process sessions with mixed ambiguity spacing.
- In addition, there is ability to adjust multipliers of ambiguity manually.

Group delay residuals with unresolved ambiguities
Ionospheric correction

- From dual band observations the group delay, phase rate and phase delay ionospheric corrections are evaluated.

- Ionospheric corrections are performed after clock breaks and ambiguity resolutions were processed.

Impact of ionospheric effect on group delay residuals
Reweighting

Observations weights calibration

- Weight calibration is performed to keep normalized $\chi^2$ equal to unit.
- Two modes of reweighting:
  - Session wide;
  - Baseline dependent.
- Reweighting is performed in conjunction with outlier elimination.

Reweighting control GUI

Reweighting

- Evaluate weight correction
  - Reweighting mode:
    - Band-wide
    - Baseline dependent
Outliers

Outliers processing

- Outlier is an observation which absolute value of normalized residual is greater than user specified threshold.

- Two modes of outliers processing:
  - Session wide;
  - Baseline dependent.

- Excluded observations can be included back in restoration action.

- Outlier elimination is performed in conjunction with reweighting.

Outliers processing control GUI

Outliers Processing

- Outliers Action:
  - Elimination
  - Restoration

- Processing Mode:
  - Band-wide
  - Baseline dependent

- Threshold for outliers (in sigmas): 3.00
- Number of iterations limit: 40
- Suppress weight correction in outliers processing

Outliers processing control GUI
Data processing

VLBI data processing

- Read observations
- Obtain single band delay solution
- Check for clock breaks
- Resolve ambiguities in both bands
- Check for clock breaks
- Evaluate ionosphere corrections
- Add to estimated parameters zenith delays and station positions
- Manually remove big outliers
- Switch estimated parameters (clocks and zenith delays) to PWL functions
- Manually remove large outliers
- Add to estimated parameters UT1 rate and angles of nutation
- Calibrate weights of observations
- Eliminate outliers
- Iterate reweighting/outlier processing
- Save results
A first public release will be in the forthcoming release of CALC/SOLVE system.

Following functions need to be implemented before the public release:

- Add ability to use external a priori information, \( \nu \text{Solve} \) uses data from databases only;
- Add additional models, \( \nu \text{Solve} \) applies models that were calculated by CALC (except tropospheric effects).

After public release we expect users feedback to improve the software.

Thank you for attention!