A Python-based tool for constructing observables from the DSN's closed-loop archival tracking data files

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Abstract

Radio science data collected from NASA's Deep Space Networks (DSNs) are made available in various formats through NASA's Planetary Data System (PDS). The majority of these data are packed in complex formats, making them inaccessible to users without specialized knowledge. In this paper, we present a Python-based tool that can preprocess the closed-loop archival tracking data files (ATDFs), produce Doppler and range observables, and write them in an ASCII table along with ancillary information.

ATDFs are the earliest closed-loop radio science products with limited available documentation. Most data processing software (e.g., orbit determination software) cannot use them directly, thus limiting the utilization of these data. As such, the vast majority of historical closed-loop radio science data have not yet been processed with modern software and with our improved understanding of the solar system. The preprocessing tool presented in this paper makes it possible to revisit such historical data using modern techniques and software to conduct crucial radio science experiments.

Motivation

The radio signals between spacecraft and Earth-based stations enable us to conduct crucial science experiments. The technique of precisely measuring the properties of radio signals provides a distinct advantage for obtaining information about solar system bodies, including the atmosphere[1], gravity field, rotational state, interior structure[2], and ephemerides[3]. Furthermore, radio science observations are crucial for studying solar dynamics, including solar wind and the solar corona[4], as well as testing fundamental physics[3]. NASA's Planetary Data System (PDS) actively archives these observations and makes them publicly available to scientists for analysis. However, most of these Deep Space Network (DSN) data are archived in very complex formats that bound the usage of data outside the radio science experts.

The paper focuses on the archival tracking data files (ATDFs), which are the earliest closed-loop radio science products packed in the DSN's TRK-2-25 format[5]. The ATDF format was used to archive crucial primitive radio science data from several NASA missions (e.g., Magellan, MGS Galellio). Given the current advancement in computing power, a better understanding of our solar system, and continuous evolution in precise orbit determination software, makes it worthwhile to revisit such historical data with modern tools. However, ATDF data cannot be directly accessed by most data processing software due to its complex format. As such, preprocessing software is required to unpack the binary fields of the ATDF data and convert them into useful observables. To our knowledge, there are no open-source tools available for preprocessing such closed-loop radio science data, which limits their useability.

Intending to address this need, we developed a Python-based tool to preprocess ATDF data and convert them into Doppler and range observables in accordance with the Moyer formulism[6]. The tool was written in Python and tested on several operating systems to maximize its usability.

Software Architecture

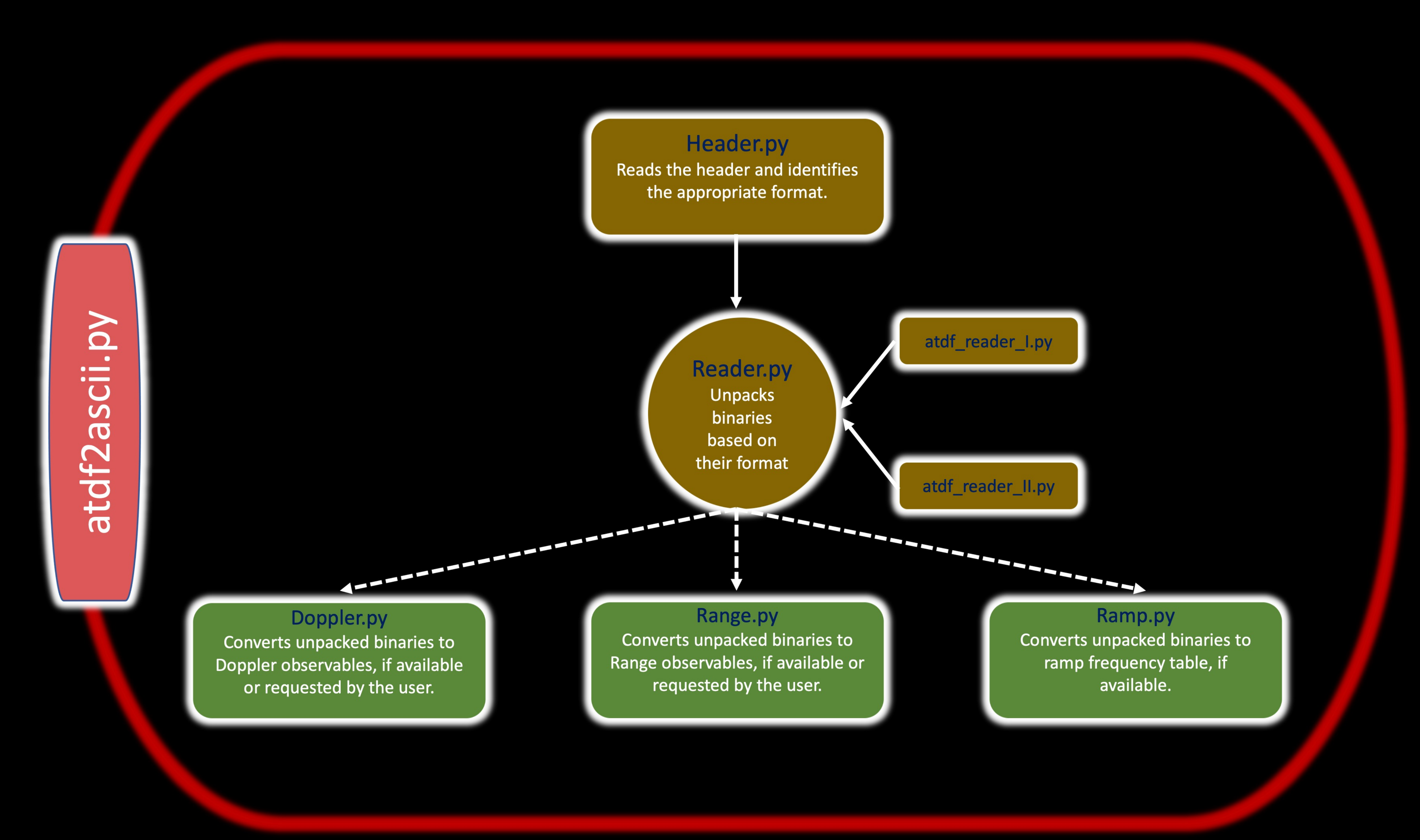

Figure 1 layouts the architecture of the ATDF software, where atdf2ascii.py is the main python script to execute the software. Based on the header information of the input ATDF file, software detects the relevant format of the binaries and unpack them using either atdf_reader_I.py or atdf_reader_II.py script. The Doppler, Range, and Ramp classes use these unpacked records and convert them into observables.

Illustrates Examples

Figure 2 illustrates the example output of the software. For demonstration purposes, we have processed two ATDF files independently. Panels A and B show the recovered Doppler observables and ramp frequencies from the Magellan mission when the spacecraft orbited Venus, while panels C and D correspond to NASA's Mars Global Surveyor mission when the spacecraft orbited Mars.

References:

1. Fjeldbo et al, 1971, AJ 76, 123, doi:10.1086/111096.
2. Verma et al., 2016, JGR 121, 1627-1640, doi:10.1002/2016JE005037.
3. Verma et al., 2014, A&A A115, doi:10.1051/0004-6361/201322124.
4. Verma et al., 2013, A&A A124, doi:10.1051/0004-6361/201219883.
5. Goltz, 2008, Trk-2-25, JPL Technical report.
6. Moyer, 2003, John Wiley & Sons, Vol 2.

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Validation

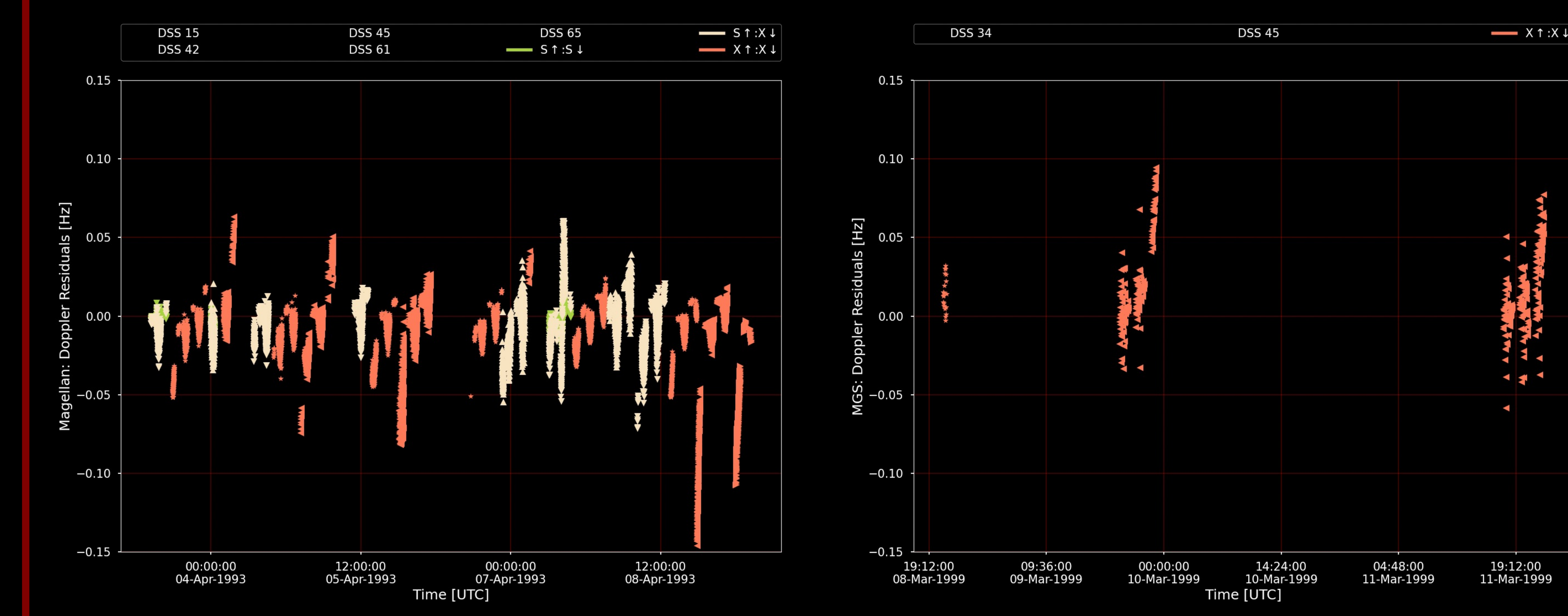

Figure 3: This figure shows Doppler residuals when the raw observables (Figure 2) are compared to predicted values obtained using the spacecraft ephemeris.

- To validate the constructed values of the raw observables, we compared them to predicted values.
- Based on Moyer's formulism[6] and the ephemerides of spacecraft and planets, the predicted values were derived.
- Magellan and MGS have root-mean-square residuals of 22 mHz and 26 mHz, respectively.
- The remaining trends in the residuals could be due to errors in the spacecraft trajectory and a misestimation of the measurement model, which didn't account for the spacecraft attitude, media delays, antenna positions, etc.
- Nevertheless, any error in the constructed values of the raw observables would have been obvious since those errors would usually be associated with offsets.

Conclusion

Deep space navigation relies heavily on radio science data. During the past half-century, these data have been used to determine the geophysical properties of solar system bodies. By the early 2000s, the DSN deprecated the ATDF format and replaced it with the TNF format to accommodate the evolution of radio science subsystems. Up until then, it was the primary closed-loop radio science data that were used widely for navigation, science, and creating a simpler closed-loop data format, ODF.

The value of historical data remains the same as when it was first acquired. In light of the current advancement in computing power, a better understanding of the solar system, and very precise software, such data sets should be re-analyzed. For instance, NASA and ESA have recently announced three missions to Venus. As such, re-analyzing Magellan radio science data with modern tools would be vital to the planning and design of these missions.

Despite being valuable science data, there are no open-source tools for preprocessing complex radio science data. This paper presents a tool that allows users to preprocess closed-loop data and create observables that can be further analyzed using orbit determination software. This tool will allow users outside of the radio science community and expertise to access historical radio science data.