Pulsar Navigation and Maser Navigation in 100 Years Starship

Dong Jiang

YunNan Astronomical Observatory

Oct 01, 2011 @ 100YSS, NASA-DARPA

Celestial Navigation

The history of navigation use celestial origin from the ancient activity which include hunting and back to home in the night or maritime activities. The base principle of celestial navigation is used the moon, stars, and planets as celestial guides assuming the sky was clear in that times. The gigantic success of celestial navigation is Christopher Columbus awareness of the American continents in the Western Hemisphere in 1492.

Traditional celestial navigation can be divided into optical stars navigation and radio stars navigation. In rainy, the conventional optical instruments can not working, so the use of time is limited. For optical celestial navigation difficult to achieve all-weather work, it has always a serious obstacle to the application of skills. The round-the-clock work is a basic requirement by modern navigation system. The use of celestial bodies to achieve the astronomical radio navigation can be out of adverse weather conditions and restrictions on day and night light. As a result, the only way of celestial navigation is radio technology to accomplish the all-weather navigation. Traditional the equipment of radio celestial navigation is radio sextant, it only receive a small number of radio signal, thus difficult to achieve continuous navigation, and just have the low navigation accuracy, and the equipment size is very big. So it is difficult to the application and the development. XNAV is developed by Sheikh et al. in recently, have achieve the preliminary results in X-ray band. Now the European Space Agency (ESA), Russia, France and German also have begun research it. However, these study is limited to X-ray band, only can be used in spacecraft navigation.

Pulsar Navigation

After radio pulsar be discovered by Bell, J. and Hewish, A. in 1967, Downs, G. S. give the advice that use radio pulsars for interplanetary navigation in 1974 [Downs, 1974].
But in that time, both the radio and optical signatures from pulsars have limitations that reduce their effectiveness for spacecraft navigation. At the radio frequencies that pulsars emit (from 100 MHz to a few GHz) and with their faint emissions, radio-based systems would require large antennas (on the order of 25 M in diameter or larger) to detect sources, which would be impractical for most spacecraft. Also, neighboring celestial objects including the sun, moon, Jupiter, and close stars, as well as distance objects such as radio galaxies, quasars, and the galactic diffuse emissions, are broadband radio sources that could obscure weak pulsar signals [Ray et al. , 2006, Sheikh, 2005, Sheikh et al. , 2006].
So Chester, T. J. and Butman, S. A. describe spacecraft navigation using X-ray pulsars in 1981 [Chester & Butman, 1981].

Radio Pulsar Navigation

Dong Jiang's analysis show that we will have the stability profile (signal-to-noise is 5) that use a 2 meters antenna observe some strong sources of radio pulsar in 36 minutes which based on the today's technology. So the pulsar navigation can give the continuous position in deep space, that means we can freedom fly successfully in the solar system use celestial navigation that include pulsar and traditional star sensor [Dong, 2008]. From our analysis, the small antenna (even two meters) or the small optical or infrared telescope (even one meter), can receive the stable pulsar signal, which means that in radio, optical and infrared bands also can achieve the pulsar navigation. This work expanded the application range of pulsar navigation, made it can use in the aerospace, aviation, maritime, ground and underwater. So pulsar navigation avoid the disadvantage of the traditional radio celestial navigation technology.

Dong Jiang give three pulsar navigation models that based on pulsar timing process and astrodynamic, and make sure that the model which based on the relationship between the accuracy of TOA and the position of the telescope is suitable for navigation. It is simple and have more advantages than the other models. In this model, the most stable pulsar PSR J0737-4715 can provide the position accuracy is 300 m and 1 us time accuracy which does not require any technological breakthroughs. The best TOA of it can have 100 ns and 30 m in the solar system which is better than star sensor [Dong, 2011].

Maser Navigation

Maser is another interested celestial in radio astronomy which has strong flux density as spectral line. A maser-based navigational system is considered by Shapiro et al. using the emissions from H_2O molecules which are the most intense in Very Long Baseline Interferometry (VLBI) navigation [Shapiro et al. , 1972]. The VLBI technique, with a master station, can use either an artificial satellite or natural sources as position references, a high-speed data link is required. The characteristics of natural radio sources, their flux, distribution on the sky, and apparent size are shown to provide a limit on position measurement precision [Knowles & Johnston, 1973]. Then Wallace, K. discuss that use radio sextant and radio star which include maser to navigation [Wallace, 1988] that just is the geometry method of traditional nautical celestial navigation. They thought the accuracy of a "radio sextant" is dependent amongst other things on the signal bandwidth, and the line emission which is typically in the region of 50 kHz is too narrow to attain reasonable fix accuracies ($<$ 10 nm) without the use of long-baseline interferometric techniques.

Dong Jiang analysis the principle of maser navigation which base on measuring Doppler shift frequency spectra and the feasibility that use the exist instrument. He give the navigation equations of maser-based navigation system and discuss the integrated navigation use maser, then give the perspective in the Milky Way and the intergalatic. His analysis show that use one meter antenna can achieve tens of meters position accuracy which better than today's star sensor [D[illegible] 2009].

Why we can use Radio Pulsar and Maser in Navigation System Today?

Your mobile phone has more computing power than all of NASA in 1969.
NASA launched a man to the moon.
You launch a bird into pigs.

Figure: Angry Birds

Figure: NASA Apollo

Why we can use Radio Pulsar and Maser in Navigation System Today?

In 1970s, radio astronomer just can use several MHz (MegaHz) band to receive signal. Now the receiver bandwidth can reach tens of GHz (GigaHz) for the technological development that include broadband feed and digital electronics et al. This is the reason that we can use small antenna to radio pulsar navigation. Maser navigation need high spectral resolution and large bandwidth that can not achieve in 1970s, but it is easy to do in todays.

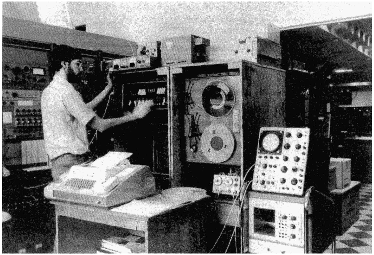

Figure: The instrument of find PSR B1913+16 in 1970s [Hulse, 1994].

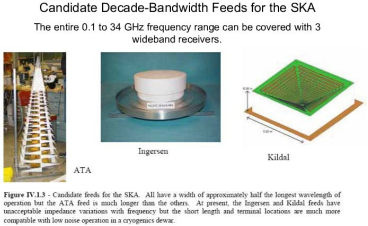

Figure: From Technology for the Next 50 Years, Sandy Weinreb @ NRAO 50th, 2007

Deep Space Network Vs Radio Pulsar and Maser Navigation

With the distance increase in deep space explore, the radiometric tracking of deep space network (DSN) will decrease in accuracy [Thornton & Border, 2005], and it can't work when spacecraft in the other side of sun. But pulsar can't be effected in that place.
The same technique can use in lunar rover, Mars rover and rover in the others terrestrials, Mercury and Venus. The virtue is obvious, when the rover in the back of the others planet or lunar, DSN can not work and human can not built GNSS for the other planet in long term. So the radio pulsar and maser navigation is one and only method at any place of the other planet surface day and night in the future explore.

Star Sensor, Radio Pulsar and Maser in Navigation

Table: Comparing in Star Sensor, Radio Pulsar and Maser

	Star Sensor	Radio Pulsar	Maser
Position	100m	30-300m(J0737-4715)	tens of meters
Time	NO	100ns-1us(J0737-4715)	NO
Velocity	0.1m/s	*	1m/s
Attitude	1”	*	*
All-weather	NO	YES	YES

This table show the navigation capability of star Sensor, radio Pulsar and maser. The asterisk means that the relevant areas being studied now and still no clearly result. We show the navigation capability of star Sensor, radio Pulsar and maser. We give the contrast that include the position, time and velocity et al. in star sensor, radio pulsar and maser. Pulsar is the only celestial which can provide time for it has a stable periodic signal in the time series. Maser can provide the best position accuracy, and it will be improved as the technology development. The asterisk means that the relevant areas being studied now and still no clearly result. Because pulsar and maser navigation run in radio waveband, its have ability of all-weather work, star sensor can not do it.

Acknowledgements

Most of words and pictures come from internet directly or indirectly that include my papers and WIKI et al.
Courtesy of WIKI et al.

40M Telescope in YunNan Astronomical Observatory

Thanks, Please give the advices and comments.
Advertisement: DJ need one PHD position in Astronomy or Astronautics, please contact him if you need someone to deal with some complex and hardcore work.

Figure: Welcome your visit and Collaboration !

Bibliography I

Chester, T.J., & Butman, S.A. 1981. Navigation Using X-Ray Pulsars.

Dong, Jiang. 2008. Pulsar Navigation in the Solar System. Arxiv preprint arXiv:0812.2635.

Dong, Jiang. 2009. MASER Navigation in the Milky Way and Intergalatic. Arxiv preprint arXiv:0901.0068.

Dong, Jiang. 2011. The Pulsar Astrodynamic Navigation Model. Submitted.

Downs, G.S. 1974. Interplanetary navigation using pulsating radio sources.

Hulse, R. A. 1994. The discovery of the binary pulsar. Reviews of Modern Physics, 66(July), 699–710.

Knowles, S.H., & Johnston, K.J. 1973. Applications of radio interferometry to navigation.

Ray, P.S., Wood, K.S., & Phlips, B.F. 2006. Spacecraft Navigation Using X-ray Pulsars. Naval Research Laboratory Review, Featured Research, 95–102.

Bibliography II

Shapiro, A., Uliana, E. A., & Yaplee, B. S. 1972. Very Long Baseline Interferometry Navigation Using Natural H_20 Sources.

Sheikh, S. I. 2005. The use of variable celestial X-ray sources for spacecraft navigation. Ph.D. thesis, University of Maryland, llege Park, United States – Maryland.

Sheikh, S.I., Pines, D.J., Ray, P.S., Wood, K.S., Lovellette, M.N., & Wolff, M.T. 2006. Spacecraft Navigation Using X-Ray Pulsars. Journal of Guidance, Control, and Dynamics, 29(1), 49–63.

Thornton, C.L., & Border, J.S. 2005. Radiometric tracking techniques for deep-space navigation. Wiley-Interscience.

Wallace, K. 1988. Radio stars, what they are and the prospects for their use in navigational systems. Journal of Navigation, 41(Sept.), 358–373.