MASER NAVIGATION IN THE MILKY WAY AND INTERGALACTIC

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ABSTRACT

The traditional celestial navigation system (CNS) is used the moon, stars, and planets as celestial guides. Then the star tracker (i.e., track one star or planet or angle between it) and star sensor (i.e., sense many star simultaneously) be used to determine the attitude of the spacecraft. Pulsar navigation also be introduced to CNS. Maser is another interested celestial in radio astronomy which has strong flux density as spectral line. Now I analysis the principle of maser navigation which base on measuring Doppler shift frequency spectra and the feasibility that use the exist instrument, and discuss the integrated navigation use maser, then give the perspective in the Milky Way and the intergalactic. After integrated with maser navigation, pulsar navigation and star sensor in CNS and inertial navigation system, is it not only increase the reliability and redundancy of navigation or guiding system but also can less or abolish the depend of Global Navigation Satellite System which include GPS, GRONSS, Galileo and BeiDou et al. Maser navigation can give the continuous position in deep space, that means we can freedom fly successfully in the Milky Way use celestial navigation that include maser, pulsar and traditional star sensor. Maser as nature beacon in the universe will make human freely fly in the space of the Milky Way, even outer of it. That is extraordinary in the human evolution to type III of Kardashev civilizations.

Subject headings: maser, celestial navigation

1. INTRODUCTION

Maser is a device that produces coherent electromagnetic waves through amplification due to stimulated emission. Historically the term came from the acronym "Microwave Amplification by Stimulated Emission of Radiation", although modern masers emit over a broad portion of the electromagnetic spectrum. Astrophysical maser is a naturally occurring source of stimulated spectral line emission, typically in the microwave portion of the electromagnetic spectrum. It was discovered by Weinreb, S. et al. firstly (Weinreb et al. 1963) after Charles Townes given prediction. This emission may arise in molecular clouds, comets, planetary atmospheres, stellar atmospheres, or from various conditions in interstellar space.

The traditional CNS origin from nautical, developed to aeronautics by US(B-52,FB111, B-1B,B-2A,SR-71,F22 et al.) and Soviet(TU-16,TU-95,TU-160 et al.(Pappalardi et al. 2001, AnGuo 2007), success in determine the attitude of the spacecraft to help orient the Apollo spacecraft enroute to and from the Moon. Although the Global Navigation Satellite system (GNSS) and Inertial Navigation System (INS) almost can finish any job in this planet now, someone still continued think it is important for it can be used independently of ground aids and has global coverage, it cannot be jammed (except by clouds) and does not give off any signals that could be detected by an the others. The traditional maritime state which include US, Russia, UK, French, all spend many money in CNS for its unique advantage.

Pulsar navigation is use pulsar as beacon give the continuous position in deep space. Dr Sheikh et al. construct the complete frame about the X-ray Pulsar-based Autonomous Navigation (XNAV) which based modern navigation technique that include Kalman filter et al (Sheikh 2005, Sheikh et al. 2007). Dong Jiang analysis the feasibility that use radio pulsar navigation and discuss the integrated navigation use pulsar, then give the different navigation mission analysis and design process basically which include the space, the airborne, the ship and the land of the planet or the lunar in the solar system (Dong 2008). With the distance increase, the radio-metric tracking of deep space network (DSN) will decrease in accuracy, and it can’t work when spacecraft in the other side of sun (Ray et al. 2008) and land rover in the back of the other planet or lunar. But pulsar can’t be effected in that place.

Now I analysis the principle of maser navigation which base measure Doppler shift frequency spectra that is the similar process of measure Doppler effect in radio navigation.

2. PRINCIPLE OF MASER NAVIGATION

Maser emission from molecules such as water, hydroxyl(�H), and silicon monoxide(‘SiO) is strong spectral line that is an important tracer of the gas kinematics and magnetic field strength in astrophysically interesting regions. Figure.1 show some examples of spectra from maser in Post-AGB Stars(Deacon et al. 2004). The order of velocity is dozens of kilometers per second in this figure. Some of it have double peaks structure for the Doppler effect that come from the rotation of star.

The Doppler effect (or Doppler shift) is the change in frequency and wavelength of a wave for an observer moving relative to the source of the waves. It is commonly heard when a vehicle sounding a siren approaches, passes and recedes from an observer. The received frequency is increased (compared to the emitted frequency) during the approach, it is identical at the instant of passing by, and it is decreased during the recesion. For waves which do not require a medium, such as light or gravity in special relativity, only the relative difference in velocity between the observer and the source needs to be considered. The Doppler effect for electromagnetic waves such
as light is of great use in astronomy and results in either a so-called redshift or blueshift. It has been used to measure the speed at which stars and galaxies are approaching or receding from us, that is, the radial velocity. This is used to detect if an apparently single star is, in reality, a close binary and even to measure the rotational speed of stars and galaxies.

According to the relativistic Doppler effect, we will have the relation between the frequency we will receive \( f' \) and the frequency the source emission \( f_0 \):

\[
\frac{f'}{f_0} = \sqrt{1 - \beta^2}
\]

where \( \beta = \frac{v}{c} \), \( v \) is the relative velocity between the source and the observer, \( \theta \) is the angle between the line of the source to the observer and the direction of the source movement, \( c \) is the speed of light.

When \( \theta = 90^\circ \), called transverse Doppler effect, we have the relation:

\[
\frac{f'}{f_0} = \sqrt{1 - \beta^2}
\]

when \( \theta = 0^\circ \) and \( \theta = 180^\circ \), called longitudinal Doppler effect, we have the relation:

\[
\frac{f'}{f_0} = \sqrt{1 + \beta}
\]

and

\[
\frac{f'}{f_0} = \sqrt{1 - \beta}
\]

In usual, the transverse Doppler effect far less than longitudinal Doppler effect, so astronomer only calculate longitudinal Doppler effect, when \( \nu \ll c \), we have:

\[
\frac{f'}{f_0} = 1 \pm \beta
\]

So the value of Doppler shift spectra

\[
\Delta f = f' - f_0 = \pm f_0 \beta
\]

In the formula,”+”,”-” correspond to blueshift and redshift.

From the above formula, if we know the frequency \( f' \) and the frequency the source emission \( f_0 \), we will have the relative velocity between the source and the observer. In astronomical observation, the velocity be normalized to the local standard of rest(LSR) for it benefit to study the celestial in a uniform frame. So I think we can use the Doppler effect to navigation. Figure 2 show the principle of maser navigation in two dimension. The center is LSR, \( V \) is the velocity of spacecraft. If we can receive two signal which come from maser sources, we will have the relative velocity between the observer(i.e. the vehicle) and the LSR. Then using the velocity plus the time, we will have the relative position between the vehicle and the LSR. The similar principle of maser navigation in three dimension, we will have the information of the continuous position in the space, if we can receive three maser signal simultaneous.

3. MASER SIGNAL PROCESS IN ASTRONOMY VS THE REQUIRES OF ENGINEER PROJECT VS THE RELIABLE OF TECHNIQUE

Maser have been found in transitions of OH, SiO, water, methanol, ammonia, and other molecules, and also in recombination lines of hydrogen. The maser observation system sensitivity i.e. the raw limiting flux density is given by the radiometer equation

\[
S_{lim} = \frac{\sigma \beta T_{sys}}{G \sqrt{BN \nu \tau}}
\]

where \( \sigma \) is a loss factor, taken to be 1.5(One-bit sampling at the Nyquist rate introduces a loss of \( \sqrt{2/\pi} \) relative to a fully sampled signal. The principal remaining loss results from the non-rectangular bandpass of the channel filters). \( \beta \) is the detection signal-to-noise ratio threshold, taken to be 8.0, \( T_{sys} \) is the system temperature, \( G \) is the telescope gain, \( B \) is the receiver bandwidth in Hz, \( N \) is the number of polarizations and \( \tau \) is the time per observation in seconds. The gain for parabolic antennas \( G dB = 10 \log \frac{4D \nu}{\lambda_0^2} \) in this form, \( D \) is Diameter of dish, \( \lambda_0 \) is center of wavelength , 4.5 is parameter which static by experience. The flux density of maser is very biggest, we can observed it even if use 5 meter antenna in microwave. For improving the sensitivity of observation system , we also can use low-noise receiver and a relatively wide bandwidth.

Maser take place in several places in the universe: in the vicinity of newly forming stars and regions of ionized hydrogen (H II regions) (OH, water, SiO, and methanol masers); in the circumstellar shells of stars at the end of its life that is, red giants and supergiants (OH, water, and SiO masers); in the shocked regions where supernova remnants are expanding into an adjacent molecular cloud (OH masers); and in the nuclei and jets of active galaxies (OH and water masers). The emission from OH masers can vary on timescales of hundreds of seconds and be detected as long-duration radio bursts(Cohen & Brebner 1985; Yudaev 1986). In the above, maser from circumstellar matter of red giants and supergiants (i.e. AGB and post-AGB) is well in navigation for some of it have double peaks structure that easily identified. The emission from maser of circumstellar matter have vary on timescales of orders of three months to years(Lekht et al. 2001; Otaka et al. 2001).

Navigation of use maser just for a continuous spectral line signal during the different mission time which during tens of minutes to several years. When I penetrate the system of maser navigation as one systems engineering, I think navigation system use maser is feasible absolutely. Some modern digital signal processing(DSP) technique can apply to maser signal navigation which include weak signal detection, signal enhancement, signal reconstruct et al. Maser spectral line is gaussian for the thermal motion of molecule, but the complex surrounding for example turbulence make profile become complex. In navigation, we just need the information from phase, so we can magnify the weak maser profile signal through normalizing it to a gaussian signal or plus a gaussian signal. The navigation system must leave a copy of raw data to astronomer for the best filter is construct a good noise model by it.

Dong Jiang analysis the special parabolic dish use in spacecraft to achieve pulser tracker, the phased array antenna to achieve pulser sensor, and the phased array feed can apply in pulser sensor when use one dish(Dong 2008). The similar technique can use to maser sensor in navigation. The phased array antenna or feed can receive several radio celestial which include different maser or pulsar simultaneous. With electronic technique development, high speed analog-to-digital converter (ADC) obtain order of Gigabyte\(^{-1}\) easily, field-programmable gate array (FPGA), multi-core multi-PC cluster and graphics processing unit(GPU) all apply to scientific
computing, and plan 9 as an open-source distributed system have been tested by the creators of Unix from Bell Labs. If the Plan 9 can fuse Multi-core CPU, GPU and FPGA, construct one computing server and use different advantage of it, That will easily finish many scientific computation which include reduce different radio sources.

In maser navigation, radial velocity measurements and the time measurements is important to have the position. The accuracy of this navigation system only depends on the accuracy of the spectrum we have obtained. The light frequency comb have developed in recently (Hall 2006; Hänsch 2006) that will play key role in maser navigation. A laser frequency comb that enables radial velocity measurements with a precision of \(1 \text{cm s}^{-1}\) (Li et al. 2008) If we can achieve the similar instrument in microwave, we can have easily finish maser navigation. The atomic clock has the advantage that keep the time in short timescale. Pulsar especially millisecond pulsars (MSP) be thought the natures most stable clocks (Taylor 1991). The data show some pulsar stability than atomic clock in timescale than one year (Matsakis et al. 1997). When integrated it, even plus light frequency comb clock in the future, that will satisfied with maser navigation.

The Kalman filter is an efficient recursive linear filter that estimates the state of a dynamic system from a series of noisy measurements (Kalman 1960). It can predict the motion of anything for it is recursive, even the signal have noise for that use the dynamic state estimate the system. In maser navigation, that is significant like it in INS and the traditional CNS (i.e. star sensor). We can use navigation kalman filter measure spectral line range, spacecraft clock, then compare with the signal which come from maser, so we will have the velocity and position through plus time.

Integrated navigation with maser between pulsar navigation, CNS and INS, even GNSS, is realistic path in the future mission. It will increase the reliability and redundancy of navigation or guiding system (Zhang Guo Liang 2008). The multi-waveband maser navigation also is interesting. In integrated navigation, system analysis and modeling, system state estimation, filter design, information synchronization and system fault tolerance filter design all is important. Dong Jiang give the different navigation mission analysis and design process basically which include the space, the airborne, the ship and the land of the planet or the lunar in the solar system (Dong 2008). The similar analysis also fit for maser navigation.

4. MASER NAVIGATION IN THE MILKY WAY AND INTERGALAXY

The virtue is obvious, when the rover in the back of the others planet or lunar, DSN can’t work and human can’t built GNSS for the other planet in long term. So the maser navigation and radio pulsar navigation is one and only method at any place of the other planet surface day and night in the future explore. The advantage of maser navigation is some of beacon that maser emission come from the nuclei and jets of active galaxies (OH and water masers) (Lo 2005). So human will have chance use it freely fly in the space of the Milky Way and Intergalaxy.

Soviet astronomer Kardashev N.S. proposed a scheme for classifying advanced technological civilizations. He identified three possible types and distinguished between them in terms of the power they could muster for the purposes of interstellar communications. The Type III civilization would have evolved far enough to tap the energy resources of an entire galaxy. This would give a further increase by at least a factor of 10 billion to about \(10^{36}\) watts (Kardashev 1964). If we want to use the resources of someplace, we must freely voyage in the that space firstly. Maser navigation must be extraordinary in the human evolution to type III of Kardashev civilizations.

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Fig. 1. some examples of spectra from maser in Post-AGB Stars Deacon et al. (2004).
Fig. 2. the principle of maser navigation in two dimension
\vec{r}_1 (OH\ maser) \quad \vec{r}_2 (H_2O\ maser)

\vec{V}

Fig. 2.—