03/4202 Feasibility study for a spacecraft navigation system relying on pulsar timing information

Type of activity: Fast Study (2 months, 15 KEUR)

The planetary exploration missions currently under study by ESA underline the need for improved spacecraft positioning systems. A future navigation system on the one hand has to outperform traditional astro-navigation but should on the other hand not consume a large part of mission budget. Disregarding the second requirement an optimal result could be achieved by several space probes distributed throughout the solar system serving as transmitters of a positioning signal analogous to the projected Galileo positioning system. As such a fleet of satellites is out of financial reach an obvious extension of this idea is the use of astrophysical objects as origins of the positioning signal.

Candidate sources for providing positioning signals are millisecond pulsars (cf. [1] for an overview on pulsar properties). Millisecond pulsars emit a sequence a radio-frequency pulses at a period of high constancy. The frequency spectrum of the signal reaches from approximately 20 MHz to 30 GHz with a typical spectral index of –1.6 thus providing higher luminosity for low frequencies. The extreme constancy of pulsar signal timing (exceeding even that of atomic clocks) has already been applied for means of positioning by using it to tie together the coordinate systems of radio astronomy and that of visible astronomy. The position of most pulsars is known up to the precision of 0.1 arcseconds.

The principle of determining positioning information from pulsar timing signals is straightforward: If a receiver changes its position with respect to a pulsar this will result in a change of the time when the pulses are received (but not in the period of the signal). This change in arrival time directly translates into an angle towards the pulsar. As the positions of the pulsars are known to high accuracy, angular information with respect to three pulsars will directly translate into position information.

Although based on a simple principle the actual realization of a positioning system based on pulsar timing faces severe technical challenges:

1. The luminosity of millisecond pulsars is very low (approx 1 Jy @ 400 MHz for the brightest of them [2]). This requires high-sensitivity radio antennas, which however have to obey the weight and power-consumption limitations mandatory for space systems.

2. Due to the large distance of the pulsars the changes of arrival time will be tiny for small changes of the spacecraft position. Even if one uses atomic clocks as a reference time onboard the spacecraft integration of the signal over at least hundred pulsar periods will be required to obtain a sufficiently precise timing information.

The goal of the study is to investigate the feasibility of a spacecraft navigation system based on (millisecond) pulsar timing. The targeted positioning precision should be 106 m. It should verify the principle mechanism of the method. In the next step the required instrument sensitivities should be determined and compared with both the current state of technology and the sensitivities achievable by envisaged technological

progress. An investigation of the usability of the X-ray signals from pulsars for navigation purposes would be desirable. Upon the results of the study the decision on the prospects of further research in this subject should be possible.

References

[1] Andrew G. Lyne and Francis Graham-Smith: Pulsar Astronomy (Cambridge 1998).

[2] D. R. Lorimer, J. A. Yates, A.. G. Líen and D. M. Gould: “Multifrequency flux density measurements of 280 pulsars,” Mon. Not. R. Astron. Soc. 273, 411-421 (1995).