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NASA TECH BRIEF

Data Processing Method for A Weak, Moving Telemetry Signal

A method of processing data from a spacecraft, where the carrier has a low signal-to-noise ratio and wide unpredictable frequency shifts, has been developed. The method consists of analogue recording of the noisy signal along with a high-frequency tone that is used as a clock to trigger a digitizer. After digitizing, spectra are taken at several points to permit fitting a polynomial to the frequency. Digital filtering techniques, in which the signal is moved in frequency in order to stay within the bandpass of the digital filter, are then applied. The filtered data are then computer processed in accordance with a digital phase-locked receiver program that gives amplitude and frequency versus time as outputs. Several iterations are required to reach the nominal level of –180 dbm, which is approximately 20 db below the threshold of the real time receivers normally used in the DSN (Deep Space Network). Non-real time processing is performed in the following steps:

(1) Digitizing and digital recording of the analogue data that has a bandwidth of over 100 kHz, along with a 320 kHz timing reference tone, on a 60 ips recorder. This recording is slowed by a factor of 16 to 3.75 ips for playback, resulting in an output bandwidth of about 7 kHz. This output is low-pass filtered to about 3.5 kHz, sampled at a 20 kHz rate derived from the timing reference tone, and written on computer 7-track digital tape units.

(2) Frequency shifting and digital filtering of the data reduces the amount that has to be processed further and also holds the frequency of the observed rf carrier as nearly constant as possible. This is desirable since the optimum processor for such a signal is much easier to synthesize in a computer than the processor for a signal whose frequency changes. Data compression is required to permit data representative of long segments of time to be held in the computer memory for further processing.

(3) Digital spectrum analysis of the filtered and shifted data, since a spectrum analyzer is the optimum estimator for the frequency of a constant-frequency sine wave of unknown phase in additive Gaussian noise. Initially, power spectra of the spacecraft's signal from successive short-time intervals are used to estimate its frequency variation as a function of time. Each individual spectrum is based on a short time interval to maintain its frequency essentially constant. Such a short time can be used only for data with a strong signal-to-noise ratio since only then is the signal strong enough to be detectable from a short observation. As the signal becomes weaker, it is necessary to use more and more data for each spectrum, which requires that the signal's frequency be constant to a specified tolerance for a longer time. This is accomplished by starting with the spectra obtained when the signal is strong and fitting a quadratic function of time to the observed change in the signal's frequency. This quadratic frequency variation is then used in the frequency shifting program to preprocess the data from the next segment of time, allowing an even longer time to be used for each subsequent spectrum so that the signal can still be detected at the decreased signal-to-noise ratio. This, in turn, permits the quadratic approximation of frequency versus time to be updated to fit this latter data. The new approximation is then used in the frequency shifting program to pre-process the following segment of data, and so on. This "bootstrapping" operation

(continued overleaf)

is used to follow the signal until it is so weak that instabilities in the spacecraft's crystal oscillator prevent sufficiently long times from being used for the individual spectrum.

(4) Processing the filtered and shifted data in a digital phase-locked loop produces a running measure of the signal's amplitude and its frequency deviation from the quadratic frequency-versus-time approximation. Once the frequency of the signal is made very nearly constant by the frequency-shifting and spectrum program, the effective bandwidth of the digital phase-locked loop may be made very narrow, and the loop can then track at very low signal-to-noise ratios.

The effect of the above processing is to take data that has been sampled at a rate of 320,000 samples per sec, and which contain a signal whose frequency varies approximately quadratically with time, and from this produce output data sampled at rates down to 800 samples per sec and containing a signal whose frequency is very nearly constant. Before processing, each reel of magnetic tape contains 28 secs of data and after processing, one reel can hold over 50 min of data. This compression is essential before the spectrum program which uses this output data, can process from sufficiently long segments of time to be able to detect the signal. The phase-lock loop program also requires data compression in order to get enough data into the computer memory to obtain phase lock and to track the signal into the low signal-to-noise ratio region.

Note:

Documentation is available from:

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