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Matched Template Signal Processing for Continuous Wave Laser Tracking of Space Debris

The build up of space junk in Earth's orbit space is a growing concern as it shares the same orbit as many currently active satellites. As the number of objects increase in these orbits, the likelihood of collisions between satellites and debris will increase [1]. The eventual goal is to be able to maneuver space debris to avoid such collisions. We at SERC aim to accomplish this by using ground based laser facilities that are already being used to track space debris orbit.

One potential method to maneuver space debris is using continuous wave lasers and applying photon pressure on the debris and attempt to change the orbit. However most current laser ranging facilities operates using pulsed lasers where a pulse of light is sent out and the time taken for the pulse to return back to the telescope is measured after being reflected by the target. If space debris maneuvering is carried out with a continuous wave laser then two laser sources need to be used for ranging and maneuvering. The aim of this research is to develop a laser ranging system that is compatible with the continuous wave laser; using the same laser source to simultaneously track and maneuver space debris.

We aim to accomplish this by modulating the outgoing laser light with pseudo random noise (PRN) codes, time tagging the outgoing light, and utilising a matched filter at the receiver end to extract the various orbital information of the debris.

Pseudo Random Codes

PRN codes are semi random codes where within one period, the sequence appears random but the pattern repeats itself every period [2]. An m-sequence of a PRN code has good autocorrelation properties where if two identical codes are in phase, then the correlation output is much larger than when the codes are out of phase.

Using this property of PRN m-sequence codes, we can generate an identical local code at the receiver. By changing the delay of the local code we can measure the propagation delay of the detected code by looking for this correlation peak when the two codes are in phase.

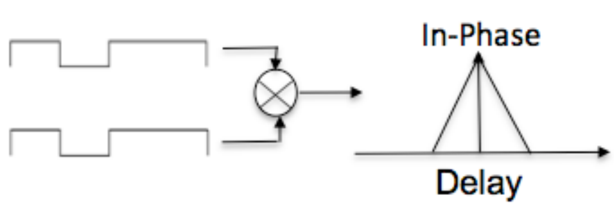

Figure 1: Showing the correlation out of two PRN codes

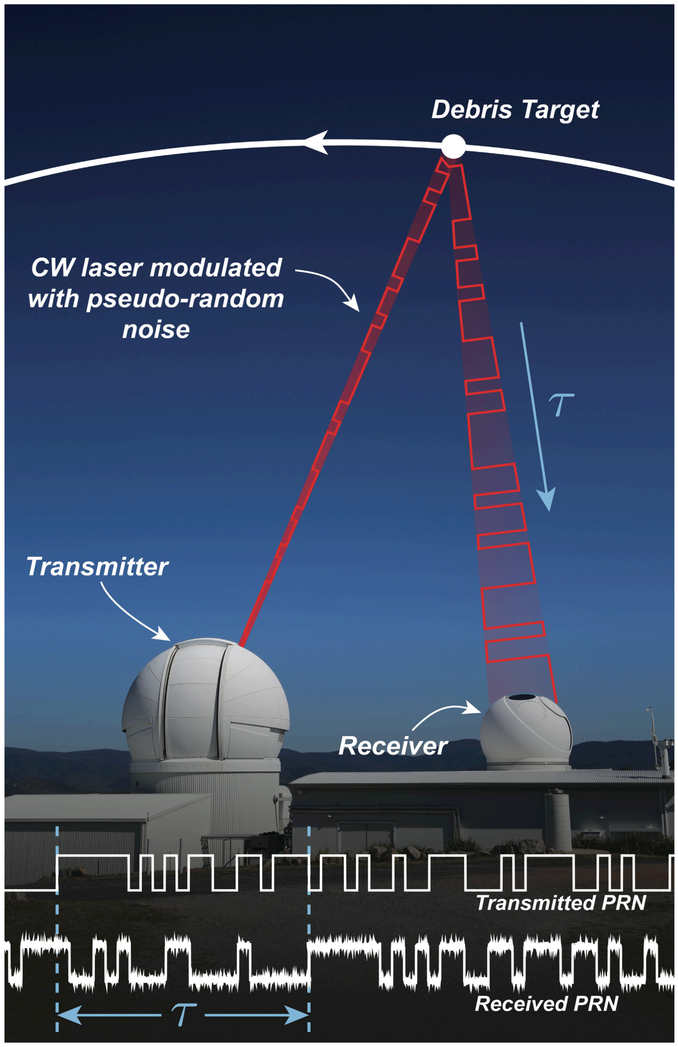

Figure 2: Illustration of a ground based Contionous wave laser being amplitude modulated using PRN codes. At the bottom of image, showing how the detected reflected signal is shifted due to the propagation delay

Space debris is not a stationary target but have very large velocities and acceleration. These changes in the propagation delays will cause subtle changes in the detected signal, which will reduce the correlation output with the local code and affect the ranging measurement. For example if the space debris is moving towards the telescope, then due to the velocity of the target debris, every bit is now arriving at a slightly smaller delay than the previous bit. This will result in the detected PRN signal to be compressed in comparison with the locally generated code. If the debris target has acceleration, then this parameter will cause a change in the rate of compression of the detected signal.

If the debris target is moving away from the telescope, every bit is now arriving at a slightly shorter delay than the previous bit and so now the detected PRN signal will be stretched when compared to the locally generated code.

Matched Filters

Matched filters have been used in many different fields for many years including in radars and even in the recent detection of gravitational waves [3]. In one of the detection, scientists were only able to identify that a signal was present in the noise by using matched filter. With the help of matched filters, their were also able to identify the celestial bodies that generated the gravitational waves by finding which parameters and parameter values best matched the detected signal.

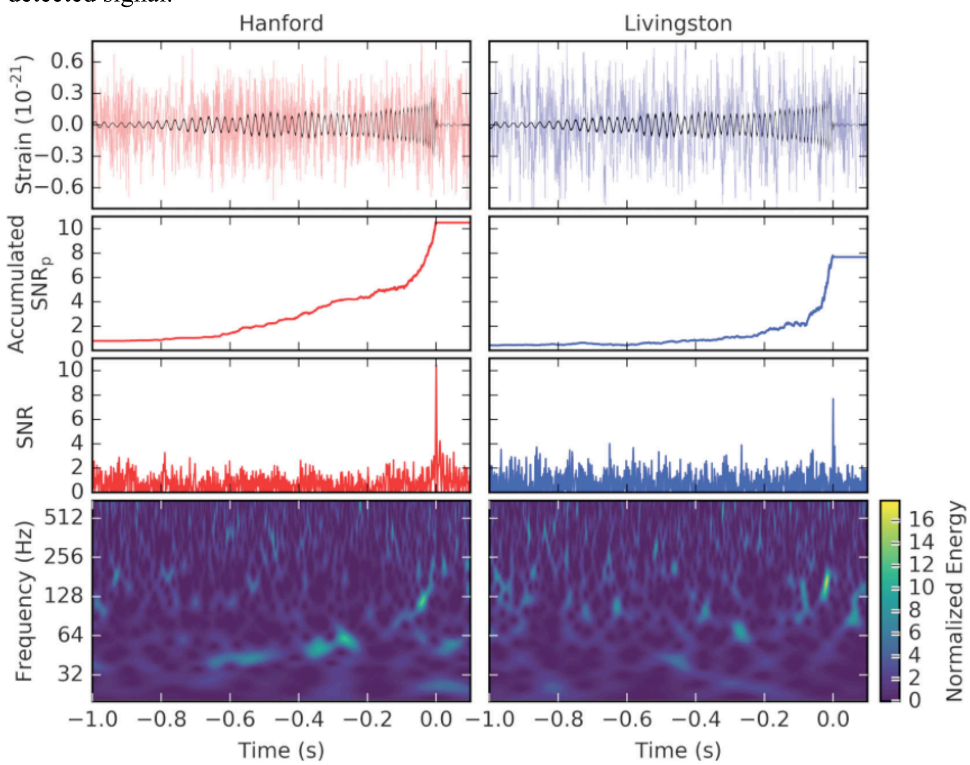

Figure 3: Detected signals from both LIGO sites in Hanford and Livingston. The top two plots show the detected strain from the detectors and the plot in balck showing the best matched signal [3].

We hope to use the knowledge gained from using matched filters in both radars and gravitational wave detection and apply it to the tracking of space debris using ground based lasers.

Enough orbital information of the debris need to known in order for the laser ranging system to acquire the debris and track it. So for our application, we have an idea of the debris position and we can use the matched filter to obtain precise measurements of the orbit. By generating a matched template that goes through this uncertainty region to fine the correct parameters that best matched the detected signal. The parameter input values will be used to recreate the effects on the locally generated PRN code.

At the correct parameter values, the output of the cross correlation will be at the maximum value. As we move away from these optimal parameter values, the cross correlation output starts reducing. By searching for these peak, we can identify the orbital parameters that best match the detected signal in propagation delay, code compression or stretching and the rate of compression or stretching.

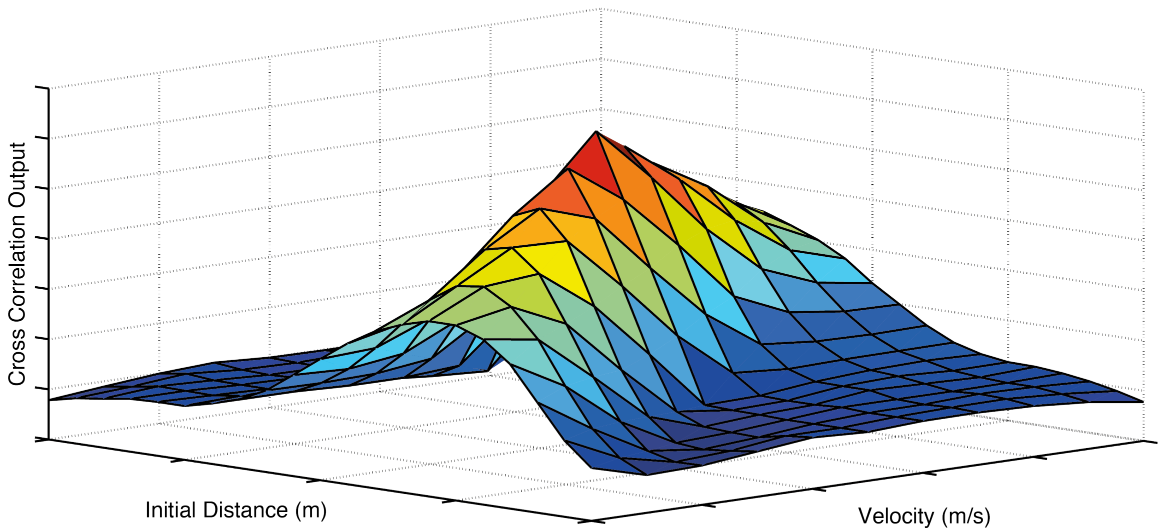

Figure 4: Cross correlation plot for matched template with varying input velocity and distance values for high SNR detected signal

1. REFERENCES

1.1 <u>Sample References</u>

1. Donald J. Kessler and Burton G. Cour-Palais, *Collision Frequency of Artificial Satellites: Creation of a Debris Belt*, Journal of Geophysical research, Vol. 83, 2637 - 2646, 1978.
2 Mutagi, R.N., Pseudo noise sequences for engineers, Electronics Communication Engineering Journal, Vol. 8, 79-87, 1996.
3 B.P. Abbott et al, GW151226: Observation of Gravitational Waves from 22-Solar-Mass Binary Black Hole Coalescence, PRL 116, 241103 (2016) 15 June 2016