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DETECTION OF RADIO FREQUENCY WAVES IN HYPERVELOCITY IMPACT AND ITS ENERGY DEPENDENCE WITH MASS AND VELOCITY OF THE IMPACTOR

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1. EXTENDED ABSTRACT

Satellites we launch into space are subject to hazards caused by space weather, incorrect orbit, internal problems and most importantly, collisions. These collisions are a result of orbital debris and meteoroids impacting the satellites and can cause mechanical and electrical anomalies. While most of the mechanical damage is well studied and is easy to diagnose, more than half of the electrical anomalies are still unknown and may be attributed to hypervelocity impact (HVI). HVI refers to a collision where the projectile speed exceeds the speed of sound in the tar-get material and its impact energy ionizes the material near the surface, generates plasma, emits light flash and depending on the impact conditions produces radio frequency (RF) emissions. It is crucial to study RF emission as it can be intercepted by the spacecraft electronics and cause electromagnetic interference (EMI), which can result in damage to vulnerable electronic components of the spacecraft.

We conducted a preliminary study on the characteristics of RF emission, mainly its energy dependence on the mass and velocity of the projectile. RF emission power is likely dependent on plasma parameters such as total charge produced in an impact, which is dependent on the mass and velocity of the impactor. The analyzed data come from a series of experiments conducted in 2011 using the Van de Graaff dust accelerator at the Max Planck Institute for Nuclear Physics. In these experiments, iron particles with various masses between 0.1 fg to 10 pg and initial velocities ranging from 2-60 km/s were used as impactors on different target materials and RF emission was captured using an array of antennas, including three patch antennas tuned to 916 MHz. Previous studies using the same set of data suggest that RF emission is linked to an impactor speed threshold of approximately 18 km/sec (A. Fletcher, S. Close, D. Mathias. Simulating plasma production from hypervelocity impacts, Phys. Plasmas, 2015) but none of its other features have been studied to date. The focus of this research is to describe our method for de-noising and quantifying the total RF signal energy to study the characteristics of RF emission in hypervelocity impacts.

The Discrete Wavelet Transform (DWT) was applied to decompose the RF signal into different frequency bands. In order to achieve high Signal to Noise Ratio (SNR) and low Mini-mum Squared Error (MSE), various wavelet threshold techniques and number of decomposition levels were examined. Overall, the Symlet wavelet of order 4 (sym4) with 4 decomposition levels, hard thresholding method, and the universal threshold technique achieved the best outcome. This denoising technique was able to detect RF emission in 17 impact events, all with tungsten as the target material, and some with concurrent RF detections across multiple patch antenna sensors. Then, to extract the signal energy at each frequency band, we applied Parseval's theorem to the RF signal. As shown in figure 1, results show that there is a potential linear relation-ship between the total RF signal energy and the energy flux of the impactor, mv^3, where m and v are the mass and velocity of the impactor respectively. As can be seen, three data points, all for the same impact event with impactor energy flux of about 14×10^{-5} kg m^3/s^3 don't follow the potential linear relationship described above. We believe experimental errors could be one of the reasons for this behavior; however, the reason is still under investigation. This relationship can further be used to determine the spacecraft risk under various impact conditions.

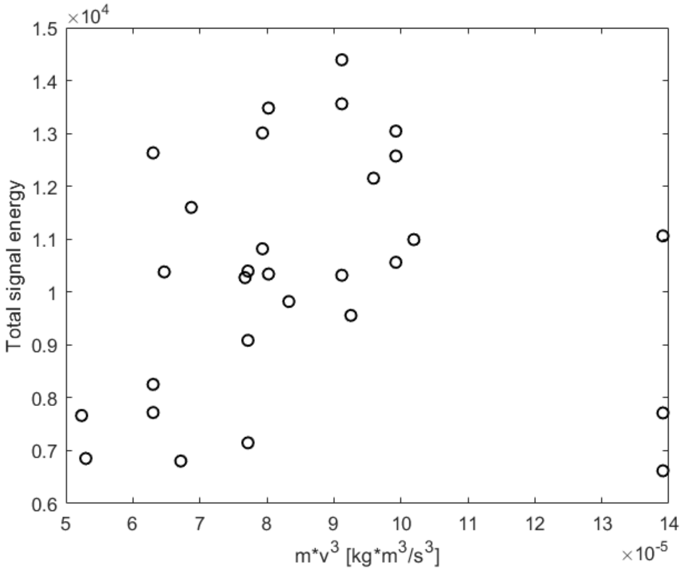

FIGURE 1. RF SIGNAL ENERGY VS. ENERGY FLUX OF THE IMPACTOR

The second part of this research focuses on using the obtained energy dependence as a feature to feed into an RF predictive calculator. This calculator uses Support Vector Machine (SVM) to perform classification on the non-linear data set. Result of the classification indicates whether or not an impact event emits RF and if the emitted RF has enough energy to cause a threat to the electrical components of the spacecraft.

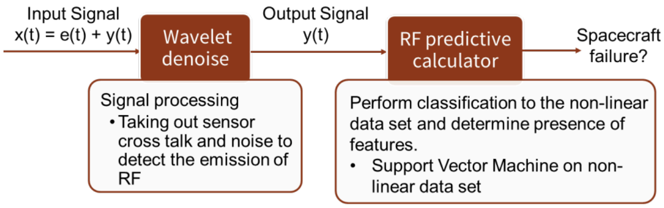

FIGURE 2. PROCESS OF DETERMINING SPACECRAFT FAILURE UPON AN IMPACT EVENT

Better understanding of RF emission will allow spacecraft design to include mitigation techniques or to improve EMI design standards to prevent impact-related electrical anomalies on future spacecraft. In addition, results of this research can provide the first steps towards under-standing the physics behind RF emission which is still under investigation.