THE ACOUSTIC SIGNALS GENERATED DURING PENETROMETER IMPACTS INTO GRANULAR MATERIALS: IMPLICATIONS FOR HUYGENS,

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Summary: The Huygens probe, currently on its way to Titan includes both a penetrometer ACC-E and an acoustic sensor ACU. To investigate whether information from these instruments could be combined to provide information about the surface properties upon impact, a microphone has been used to record the sounds of impact of an instrumented penetrometer (an early ACC-E prototype). Analysis of the sounds generated from impacts into two different target materials indicate that ACU will in theory detect the ACC-E penetration, but the signal to noise ratio is unlikely to be better than 2 (1.5 to 4), and that telemetry constraints imposed by Huygens mean that only 2 or 3 points of data will be taken during the impact event. In addition to this, ACU will only be active for 410ms in every 2s, so the sensor may actually not be on at impact. Investigation of the sounds generated by penetrometer impacts within the laboratory indicate that frequency analysis of results from an acoustic sensor can be an additional useful tool for resolving material properties in a terrestrial environment.

Introduction: Penetrometry is extensively used in the analysis of soil properties, primarily for geological and construction applications. Usually such measurements utilize a cone penetrometer device (CPT) that is pushed into the material at a constant rate, whilst information is recorded from various sensors incorporated into the penetrometer[1]. However the field of dynamic penetrometry, with the penetrator impacting freely onto the material has been less well studied (apart from military work) but is however relevant to various upcoming and historical space missions[2].

The Huygens probe incorporates both a tip force penetrometer sensor, ACC-E within SSP[3], and an acoustic sensor, (ACU) within HASI[4]. To investigate the possibility that these sensors may be combined to further constrain the material properties of Titan's surface, one must consider the effect of Titan's atmosphere as well as the sensitivity and frequency range of the ACU and the data processing carried out by the probe before returning the ACU data.

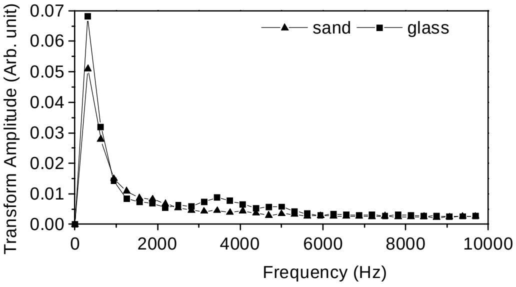
Terrestrially, there have been previous studies of acoustic sensors fitted to CPTs "listening" to the material-penetrometer interactions to distinguish between soil types by frequency analysis (as opposed to acoustic velocity measurements)[5,6,7,8]. Tringale and Mitchell[5] found that for fine sand, signals were concentrated in the frequency range of 2-5KHz, comparable with the frequency range of 0-7.5kHz of the ACU. In agreement with Villet et al[8], they were easily able to distinguish between different soil types.

Apparatus and method An early prototype of ACC-E has been combined with a simple directional microphone and sampling equipment. The penetrometer is released into a container of the target material from a known height. The penetrometer was fitted with a tip force sensor and an accelerometer, allowing reconstruction of the velocity and position time history of the impact event. For the acoustic measurements, an electro-condenser directional microphone, (0 to 20kHz), was sampled at 40kHz.

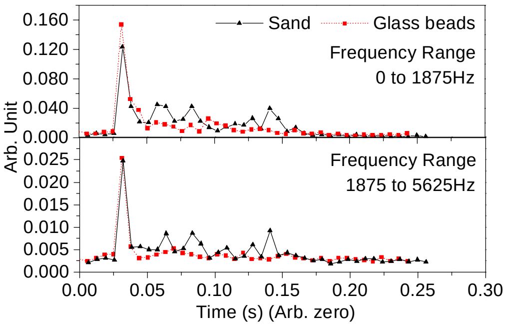
Onboard Huygens ACU processes sound data in two ways: The detector samples every 64μs, 64 times, then a Fourier transform is taken giving 32 bins of 240Hz width (i.e. 0-7680Hz). This is repeated 80 times, and mean transform is then produced, which is returned to Earth as 8 bit readings on a log amplitude scale. Secondly, every second transform is recorded as two 4-bit numbers representing the mean amplitudes of the frequencies over 0-1850Hz and 1850-5620Hz giving 40 sets of 2x4bit numbers. These two data acquisitions are taken concurrently over approximately 410ms, which is repeated every 2s, as the sensor is time multiplexed with other sensors in the HASI suite. On Earth one may of course look at the unprocessed signal as well for additional information.

Two different target materials were studied: kiln dried common sand and graded glass beads 150μm diameter. The glass beads are an "ideal" material, being spherical and all of similar known size. Sand is a more realistic material, and it was also felt that the non-uniformity of the grains would act to enhance the noise levels produced. To prevent variation in target behavior, the target was always freshly poured *in situ* at a constant filling rate from a 10cm drop height. Compaction was characterized as detailed in Garry et al[2].

Results and Discussion: First we consider the viability of HASI detecting the acoustic signal from ACC-E on impact. A mean signal amplitude over the frequency range of 0-8kHz over a series of ten impacts into sand was recorded and found to vary from 25 to 52mPa, with a mean value of 30mPa. If this sound were to occur on Titan, then using the standard Titan atmosphere model[9], the estimated signal at ACU is 20mPa, compared to the threshold of the ACU microphone of 10mPa. This gives a signal to noise ratio of just 2.



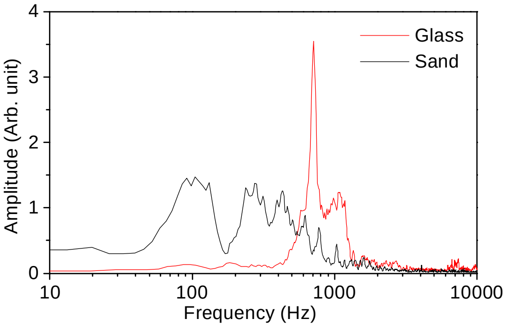
One can then apply the various Huygens data reduction schemes to the data recorded. The averaged 80 Fourier Transforms taken during impact are shown in the above figure for glass and sand. The form of the two acoustic curves is very similar, apart from changes in amplitude of the low frequency peak and between 1 to 3kHz It is unlikely that these small differences in signal levels would still be apparent after the Huygens averaging process, which may inadvertently incorporate signals recorded once the body of the probe touches down. Hence with a peak signal just above the noise floor any low amplitude structure will not be seen.



Processing in the HASI higher time resolution manner gives the above figure. In both frequency regimes, the sand signals have more scatter compared to glass beads. The sand is generating a broader spread of frequencies that is also being sustained for longer time periods, even continuing after the penetrometer has come to rest.

ACU may detect variation in the height of the low frequency peak in the averaged data, and the height of the peak at impact in the 0-1875Hz range. However, in both cases this difference is of the order of 10%, and should be compared to a predicted signal to noise ratio of 2.

Laboratory based investigation The figure below plots the Fourier transform of the acoustic signals recorded of the impact event with no data compression. In general the spectra are featureless above 8kHz, with only slight structure above 5kHz, almost identical to the observations of Tringale and Mitchell[5].



The glass data curves all have a sharp peak, whereas sand generally exhibits a broader spectrum, and shows variation of up to 20% in peak height from drop to drop. Although one cannot currently allocate specific meaning to particular frequencies, one is able to demonstrate clear differences between material structures.

General discussion further effects that require study are material cohesion, over-consolidation or the presence of liquids. From the data above, the acoustic signals generated in dynamic penetrations in terrestrial environments can help resolve ambiguities in tip and acceleration data, especially if direct access is difficult.

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