PHOTOMETRIC TECHNIQUES FOR LANDER SITE CERTIFICATION. Nicholas D. Efford, IEBS, Environmental Science Division, University of Lancaster, Lancaster LA1 4YQ, U.K.

In view of the need to safeguard wideranging scientific objectives and a considerable investment of human effort and funding, the certification of an acceptable landing site is of paramount importance in any spacecraft mission involving the deployment of an unmanned lander probe. In the case of Viking, boulders greater than 0.22 m in size represented potentially fatal hazards, yet features smaller than roughly 100 m across could not be recognised in the images used for site certification [1]. As even a cursory examination of the Viking Lander images will illustrate, the techniques employed to circumvent this problem, namely the extrapolation of visible detail down through more than two orders of magnitude coupled with the utilisation of Earth-based radar roughness measurements [2], are of limited value; the assumptions inherent in the former may be unjustified, whilst the latter suffers from poor spatial resolution and ambiguities in interpretation, in that, for example, the penetrating character of electromagnetic radiation may result in the detection of sub-surface roughness not necessarily indicative of unduly hazardous surface topography. Site reconnaissance at extremely high (i.e. 1 m pixel^{-1} or better) resolution, such as that recommended for future Mars missions [3], is a direct yet in many ways impractical solution, given optical system design technicalities and the number of images that must be acquired to adequately cover the areas targetted by landing ellipses. There is thus a need for economical methods of hazard detection that operate at sub-pixel scales and make use of existing, commonly-employed spacecraft instrumentation, such as the imaging system itself.

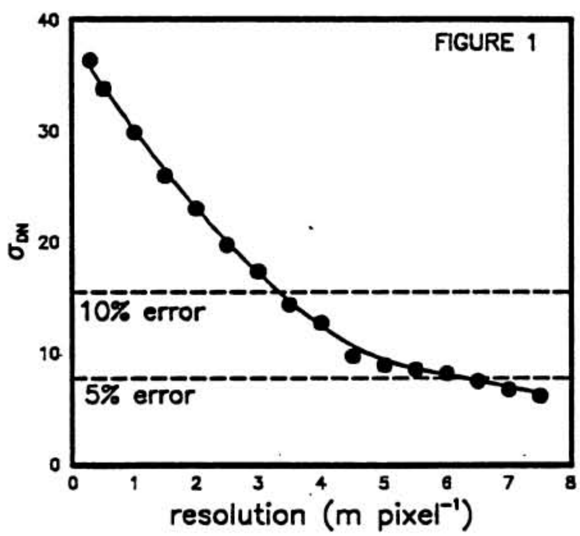
Pixel-Scale Feature Detection. Positive-relief features on a flat plane will in general have a bright sunward-facing side abutting a darker side, which is tilted away from the Sun and possibly in shadow, given a sufficiently high incidence angle. The net effect on pixel reflectance will be minimised if the bright and dark sides of the feature are wholly contained within the projected area of a single pixel. It is statistically likely, however, that some objects will be favourably positioned so as to produce a detectable signature in the image, namely one or more anomalously bright pixels immediately adjacent to one or more anomalously dark pixels. This signature has been identified in a small subregion of a Viking Orbiter frame containing the site of the Mutch Memorial Station, and has been interpreted as signifying the presence of a boulder roughly 10 m across [4].

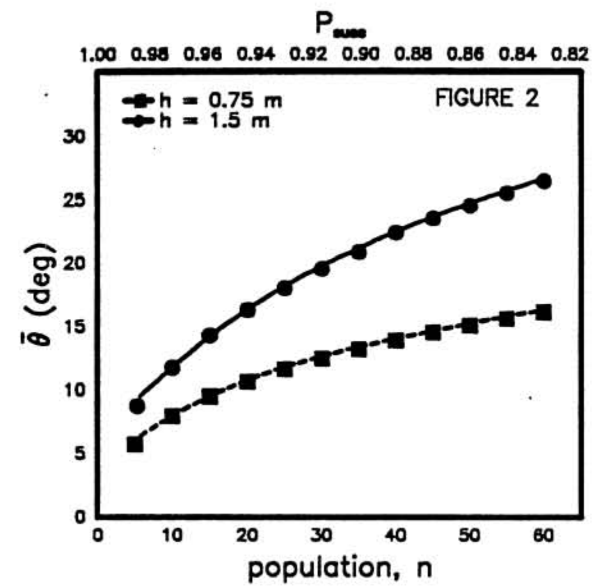
To determine the limits of detectability for such anomalies, a digital terrain model (DTM) was constructed by the emplacement of randomly-located obstacles, each of uniform size with a parabolic or conic cross-section. An initial synthetic image was generated from the DTM under near-optimum conditions of viewing and illumination (zero emergence angle e and moderate-to-high incidence angle i) by the method described in [5], and this was artificially degraded by the enlargement of pixel size to produce images with a range of spatial resolutions. Figure 1 plots the standard deviation of imaging pixel DN against image resolution for a DTM populated by 40 cones with base radii of 1.5 m and heights of 2 m. A Lommel-Seeliger surface scattering law with $i = 60°$ was assumed. The horizontal dashed lines indicate points at which the anomaly becomes statistically insignificant, for a given error in pixel DN. Clearly, if unrealistically-extreme aspect ratios are ignored, this technique is of little use for obstacles smaller by a factor of two or more than the size of an imaging pixel.

Sub-pixel Scale Feature Detection. Given suitable images of the potential landing site obtained under a variety of viewing and illumination conditions, it is possible to fit Hapke's bidirectional reflectance equation [6] to photometric measurements in order to derive an estimate of $\bar{\theta}$, a parameter generally corresponding to the mean slope angle of unresolved surface roughness. The principal requirement is the availability of high phase angle data, and since survey images are likely to be acquired at or near $e = 0°$, this translates in practice to the requirement that the maximum value of i is large. Under such conditions, the presence of unresolved shadows will darken a pixel in a manner quantified by $\bar{\theta}$. The relationship between this parameter and the probability of a successful landing was investigated by using the previously-described synthetic topography and modelling the photometric properties of surface material with Hapke's equation, setting $\bar{\theta} = 0°$ and the remaining parameters to arbitrary values. Average DTM reflectance was computed for a range of incidence angles, and the resulting data were used to solve for $\bar{\theta}$ only, as described in [5].

Figure 2 plots $\bar{\theta}$ against both the population of hazardous obstacles, n, and the probability of success, P_{succ}, the latter being determined for features with a circular base of radius r in a square pixel of size x by the equation $P_{succ} = 1 - (n\pi r^2/x^2)$. Here, $r = 1.5$ m and $x = 50$ m. A clear relationship between $\bar{\theta}$ and P_{succ} exists, but an observed photometric roughness of 15° may imply probabilities of either 96% or 84%, depending on the height of the obstacles. The usefulness of this technique will therefore be somewhat limited without contraints on the morphology and size distribution of obstacles at the proposed site. In the case of Mars, it might be possible (though not necessarily appropriate) to derive these constraints from Viking Lander images. More practical limitations result from the accuracy with which $\bar{\theta}$ can be estimated from inevitably sparse orbital imaging data; restricted phase angle coverage or the assumption of incorrect Hapke parameters in constrained fits of $\bar{\theta}$ can have a serious effect [7]. Recent photometric studies of dust deposits in the vicinity of the Mutch Memorial Station [8] provide Hapke parameter estimates that might be applicable in those cases where it proves necessary to assume values for all parameters other than $\bar{\theta}$, though further careful investigation of the photometric properties of martian terrain is evidently required.

In conclusion, neither technique can be expected to provide accurate quantitative estimates of landing success probabilities, given the large number of potential sources of error that exist. However, it is envisaged that both could usefully supplement existing methods; the cumulative application of a wide range of techniques can only improve the reliability of the certification procedure and hence the likelihood of a successful landing on Mars, or for that matter, other bodies in the solar system.





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