DO WE REALLY NEED TO PUT STEREO CAMERAS ON LANDERS? A. C. Cook[1], [1]Scool of Computer Science and IT, University of Nottingham, Nottingham. NG8 1BB, United Kingdom (Email: acc@cs.nott.ac.uk.

Introduction: Stereo camera systems have been used on numerous planetary landers/rovers such as Lunokhod [1], Viking Lander [2], Mars Pathfinder [3] and the Mars Exploration Rovers (MERs) [4]. These cameras are used to provide stereo imagery from which navigation judgments or local Digital Elevation Models (DEMs) can be produced. The DEMs have the following uses:

1. To measure locations of rocks and the gradient of the terrain for vehicle navigation
2. To measure rock size and distribution statistics for geological studies
3. To determine the times at which shadows from rocks might obscure illumination of solar panels or block radio communication with the Earth or an orbiter
4. Virtual reality models for the public/media
5. To measure/verify positions of a robot arm/tool with respect to a target
6. To measure the depth profile of excavated trenches
7. To measure slope direction and gradients of the surface in order to be able to apply full radiometric correction to images for photometric studies

The use of two or more cameras incurs costs from weight, electronics needed, and power requirements. This abstract will present arguments for four practical alternatives whereby just one camera could be used by a lander/rover for producing a DEM that can satisfy all of the above uses.

What cartographic accuracy is required?: Surprisingly, only 5-7 from above list of uses need a detailed DEM with mm-cm levels of accuracy/spatial resolution. The other uses require a more sparse set of X,Y,Z measurements so long as these satisfy the tolerances needed e.g. does one need to measure the dimensions of a rock to a precision of 1% or would 5-10% do?

What are the alternatives to stereo?: Four alternatives are considered:

Camera Motion. Stereo (CMS) This applies only to rovers and utilizes displacement stereo from different positions to build up a DEM at right angles to the displacement direction. Alternatively zoom stereo, utilizing radial displacement, can be achieved by pointing a camera forwards as the rover drives along. There is also an effect of scale change that can be utilized to determine distance in that the angular size of objects increases in a known way as one approaches them.

Virtual Stereo Models (VSM). This assumes that a reasonable DEM has been produced already either from high resolution orbital imagery, or from descent imagery [5] prior to landing. Consequently the spacecraft location and location and sizes of major rocks can be gained by fitting the lander monoscopic images to a landmarks in a pre-existing DEM..

Robot Arm Scanning Mirror Stereo (RASM). Here a light weight optically flat mirror is placed on the robot arm wrist (see Fig 1 (top) R and bottom (B)). The arm is commanded to scan and rotate the mirror so that it is visible both in the lander camera and can scan the scene around the lander. Stereo matching would take place between regions of the terrain seen both in the direct lander image of the scene and from the reflected image in the robot arm mirror. Digital encoders will give an approximate position and orientation of the mirror image, from which a full photogrammetric bundle adjustment can be made to model the DEM. The larger the diameter of mirror that can be used, then the fewer stereo pair images will be required to map the scene.

Fig 1 (top) Camera (C) and robot arm (R). (bottom) Object (A) and reflection of object in mirror (B) attached to robot arm wrist.

Passive Structure Light (PSL). This would utilize the knowledge of the spacecraft position, the known altitude and azimuth of the Sun in the sky, and several hundred small optically flat light-weight mirrors positioned over the spacecraft body. Each mirror will reflect a spot of sunlight onto the surface that can be captured by the camera at distances from a few cm to tens of metres. The brightness of each sunspot will vary from the strength of full direct sunlight for close range down to the inverse square root of the mirror to Sun angular diameter ratio - as seen from the illuminated portion of the surface. Time lapse images should be taken and low data content difference images can be transmitted back to Earth. As the sunspots move across the surface they trace out curves that are modified by the local topography (see Fig 2 (bottom)). The main problem of this technique is to determine which mirror has produced which spot. This could be achieved by using different size or shape mirrors or by looking for cross-overs of sunspot trails on different days. Once mirror:sunspot identity has been established a simple stereo ray intersection between the reflected sunbeam and the position of the sun spot in the image can yield X,Y,Z coordinates. In addition range measurements may be assisted by studying the size of the sunspots in the foreground when the angular size of the Sun is less than the mirror diameter as seen from the respective illuminated surface patch. Surface slope information can be studied easily by measuring the ellipticity and orientation of each sunspot.

Discussion: Four techniques have been discussed that could eliminate the need for including stereo cameras on landers and rovers. This would reduce mass and the electronics needed and a monoscopic camera can include a more elaborate filter system than can be fitted into conventional stereo camera systems.. There are however some disadvantages: CMS will not work for landers. VSM requires very high resolution stereo from orbit or from a descent imager. . RASM and PSL will suffer if the mirrors become dusty, although the same is true for the camera optics in all 4 techniques. RASM will only work if a robotic arm is present. Finally PSL is dependent upon sunlight - if the lander is in shadow it will not work however this may be a significant problem for solar panels too. Furthermore PSL will not function well in a dusty or opaque atmosphere where atmospheric scattering prevents a clear view of the Sun. It will however work very well on bodies with no atmosphere such as the Moon, and asteroids. PSL will be particularly effective if sun spot maps are built up over several days as the Sun changes declination in the Sky. As uses 5-7 are not particularly time dependent, then this would be a very suitable technique. PSL can even be used for rovers at a very simple level in order to work out distances to rocks along a drive route if a sufficient number of mirrors are present to capture sunlight from most directions.

References: [1] Gatland K. (1978) Robot Explorers: The Encyclopedia of Spaceflight in Color, Macmillan. [2] Liebes S. and Schwartz A.A. (1977) *JGR, 82*, 4421-4429. [3] Kirk R.L. (1999) *JGR, 104(E4)*, 8869-8887. [4]. Maki et al. (2003) *JGR, 108(E12)*, 8071. [5] Li R et al (2002) *JGR, 107(E11),* 10.1029.

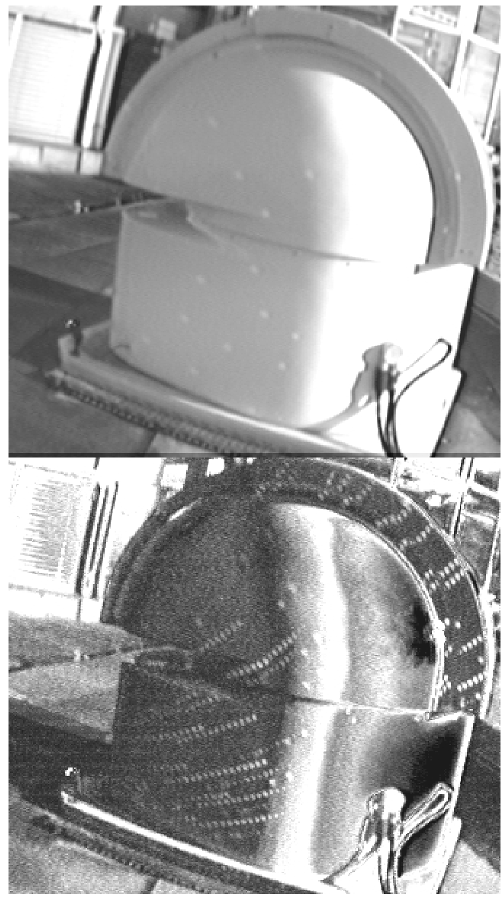

Fig 2 (top) sunspots from approximately twenty 8x8mm mirrors sited approximately 3 metres away from the target. (bottom) images of sunspots at 2 minute intervals.