AUTOMATIC RECOGNITION OF CRATER-LIKE STRUCTURES IN TERRESTRIAL AND PLANETARY IMAGES. Jon Earl[1], Agustin Chicarro[2], Christian Koeberl[3], Pier Giorgio Marchetti[4], and Martin Milnes[1], [1]LogicaCMG UK Ltd (Space & Defense Division), Chaucer House, The Office Park, Leatherhead, Surrey KT22 7LP, United Kingdom (Jon.Earl@logicacmg.com; Martin.Milnes@logicacmg.com); [2]ESA/ESTEC, Scientific Programme, Keplerlaan 1, 2200 AG Noordwijk, the Netherlands (Agustin.Chicarro@esa.int); [3]Department of Geological Sciences, University of Vienna, Althanstrasse 14, A-1090 Vienna, Austria (christian.koeberl@univie.ac.at); [4]ESA/ESRIN, Earth Observation Programme (EOP-GDR), Via Galileo Galilei, I-00044 Frascati, Italy (Pier.Giorgio.Marchetti@esa.int).

Summary: Impact cratering is a fundamental process acting on solid bodies of the solar system. The detection of impact craters on Earth may be aided by recent advances in remote sensing technologies, although visual inspection of large number of satellite images are probably too time consuming. We describe new efforts regarding recognition and detection of impact craters on Earth and Mars by using remote sensing images. In particular, approaches based on the Hough Transform and on the Radial Consistency measure are considered and compared.

Introduction: Impact cratering is recognized to be a dominating (if not the most important) surface-modifying process in our planetary system. Detecting impact craters on Earth is difficult, mostly because terrestrial processes (weathering, plate tectonics, etc.) either cover or erase the surface expression of impact structures on Earth. Many impact structures are covered by younger (i.e., post-impact) sediments and are not visible on the surface. Others are destroyed by erosion. Recent advances in Earth Observation, i.e., the availability of synthetic aperture radar (SAR) and multispectral images covering most of the Earth from scientific missions (e.g., ENVISAT, MODIS), can aid the search for terrestrial impact craters through image processing for the identification of crater features, their detection, and possible recognition. Although it is not possible to unambiguously confirm that a crater-like feature on Earth is of impact origin just from remote sensing, such data can identify potential candidates for further studies. Information that can be derived from remote sensing products refers mainly to crater morphology, which, using relevant criteria, can aid in the identification of potential impact craters.

Geological Background: On Earth, *simple* craters have diameters of up to ≤2 to 4 km, and *complex* craters, which are larger and have diameters of ≥2 to 4 km (the exact change-over diameter between the crater types depends on the target rocks). On Mars, this change-over diameter is ca. 10 km. Complex craters are characterized by a peak or peak ring of rocks that are uplifted from greater depth and would not normally be exposed on the surface. Fresh simple craters have an apparent depth (measured from the crater rim to present-day crater floor) that is about one third of the crater diameter, whereas that value for complex craters is closer to one sixth. In reality, most craters are shallower because of erosion and/or infilling (e.g., by crater lakes).

Crater Recognition: On Earth basically all small craters are relatively young, because erosional processes obliterate small (0.5–10 km diameter) craters after a few million years, causing a severe deficit of such small craters. In terms of cratering rates, there are many craters left to be detected (e.g., [1,2]). In this context, we address the issue of recognition and detection of impact craters on the Earth by applying processing techniques to Earth Observation products, complemented by digital elevation data (DEM), to automatically highlight potential targets for future exploration.

Algorithm: Impact craters on the Earth exhibit a much greater degree of variation than impact craters on other planets. Concentrating too heavily on specific crater morphology can be misleading, since similarly sized impact craters on the Earth's surface often exhibit contrasting characteristics. For our purposes we begin by characterizing impact craters in a very simple way by using their circular shape as the main feature. Although this is an oversimplification, it provides a first order approximation which allows a given algorithm to operate on data obtained from different planets and from different sensors (optical, multispectral, SAR, DEM, etc.). On the other hand this approximation reduces the accuracy of the detection process, necessitating the introduction of further steps to reduce the number of false alarms.

A previous study [3] examined the use of a modified Circular Hough Transform to provide this model. This type of algorithm works best on binary edge-detected (or gradient) images. Where the circular features are not clearly discernable in the original image, edge-detection is unlikely to result in identifiable circles that would fit the simple circle model.

The Radial Consistency algorithm developed as part of this work models impact craters as having localised rotational symmetry- this replaces the Circular Hough Transform test (that each pixel (x,y) lies on the circle defined by the triple {a,b,r} with the test that the pixel lies within a region of rotational symmetry centred at (a,b). The peaks in the parameter space {a,b} then correspond to the most likely locations of these regions of rotation symmetry in the input image. This allows partially circular features to be picked up, and provides a natural way of fusing the results from multiple data sources.

Subsequent to the detection of potential crater candidates in multiple data sets further analysis can be performed (using, for example, the morphological rules of thumb specified above) to remove circular non-crater-like features from consideration.

Prototype Tool: A prototype impact crater detection system has been developed and was successfully used to identify a number of known terrestrial craters, and has the potential to search other areas of the Earth for previously undiscovered candidate sites. The prototype system comprises two parts: (i) An interactive standalone tool, for the development and refinement of crater detection and filtering algorithms, which is designed for use with relatively small satellite image scenes; (ii) A more comprehensive batch-processing tool, for the offline processing of large areas of data. The results may be output in various formats for rapid assimilation and assessment of the identified crater candidates. The core stages of processing involved in the detection of crater candidate sites are:

- Import data from a range of different sources, in our case multiple satellite sensor data.
- Pre-processing of the input data.
- Automatic detection of circular features.
- Filtering of features based on crater-like characteristics.

This generally results in a small number of likely candidates, which then need to be expertly assessed, in order to determine whether or not further analysis is required.

Results: A number of sites have been processed as part of the prototype development phase. Fig. 1 shows the results of the prototype applied to a typical MOLA image of the Martian surface, Fig. 2. shows the results obtained by combining SAR, Landsat and SRTM datasets along with a morphological post-processing step for the Brent crater in Canada.

Discussion and Conclusions: The early results of this study are very encouraging and have shown how the use of data fusion techniques combining multispectral and DEM datasets can aid the detection process. However, the tests carried out show the limits of exploiting only a shape-based approach in the detection process. Despite some encouraging results on the exploitation of the infrared band in subtropical desert areas and even at very high latitudes, it was not possible to identify a specific band combination more suitable than others for impact crater detection.

This highlights the need to include in the proposed architecture more advanced and specific procedures to use all the information present in the sensor data to increase the detection accuracy.

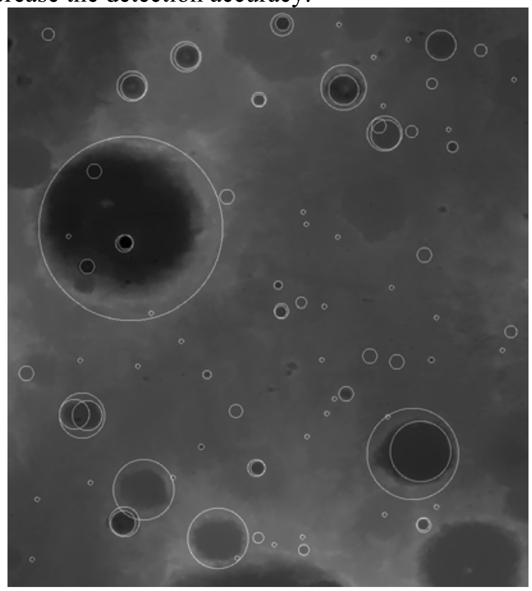

Fig. 1. MOLA data.

Fig. 2. Landsat (3,2,1) Brent crater on right.

Acknowledgements: This work is supported by the European Space Agency - ESA.

References: [1] Shoemaker E.M. et al. (1990) In: *Geological Implications of Impacts of Large Asteroids and Comets on Earth* (L.T. Silver and P.H. Schultz, eds). GSA-SP 247, pp. 155-170. [2] Trefil J. S., and Raup, D. M. (1990) *J. Geol.,* 98, 385-398. [3] Craters Study – Executive Summary ESA CR July 2002 http://www.esa.int/gsp/completed/ExecSumAll01_A19.pdf