3D Imaging and Modelling with a Space-qualified Laser Camera System: Development of Terrestrial Applications and Potential for Planetary Exploration. R. Herd[1], J. Spray[2], C. Samson[3], S. Miller[3] and I. Christie[3], [1]Geological Survey of Canada, Natural Resources Canada, 601 Booth Street, Ottawa ON K1A 0E8 herd@nrcan.gc.ca , [2]Planetary and Space Science Centre, University of New Brunswick, Fredericton NB E3B 5A3 jgs@unb.ca ,[3]Neptec Design Group, 302 Legget Drive, Ottawa ON K2K 1Y5 csamson@neptec.com , smiller@neptec.com , ichristie@neptec.com .

Introduction: Neptec's Laser Camera System (LCS) is a 3D auto-synchronized scanner whose design originated at the National Research Council of Canada (NRC). Two high-precision galvanometer-mirror combinations steer a laser beam and illuminate a target point in space. The LCS is a versatile instrument that can operate both in imaging and centroid acquisition modes. In imaging mode, the LCS raster scans objects and computes high-resolution 3D maps of their surface features. For each point imaged, the LCS records spatial coordinates (X,Y,Z) and the intensity (I) of the diffusely reflected laser signal. In collimated laser configuration, the LCS has a range precision of 0.1 mm at 1 m, 2 mm at 5 m, and 5 mm at 10 m. In focused laser configuration, the LCS can be used for very detailed imaging tasks requiring sub-millimeter precision. In centroid acquisition mode, the LCS determines the location of discrete target points on an object. In 1999, Neptec licensed this technology from NRC for space applications. With support from the Canadian Space Agency (CSA), Neptec introduced significant changes to port the original laboratory scanner to the space environment. The LCS was tested in August 2001 during Mission STS-105 of Space Shuttle Discovery; it acquired 4 high-resolution 3D images of Canadarm2 and of space station elements, and more than 2 hours of centroid data[1].

Geomaterial Classification with LCS: The combination of high resolution spatial and spectral data make the LCS ideal for geomaterial characterization and analysis. We present some early results of a research project that will eventually develop techniques for using LCS data to automatically classify geological samples based on target material texture analysis. Specifically, we present images of a variety of rocks and rock types and demonstrate that these images contain enough information to permit accurate geological classification using no other information. For example, the images of a wall made of building stone reveal that the LCS data alone is sufficient to allow identification of the rock type and its origin. The high degree of resolution reveals that the stone is a well-layered, fine-grained sandstone of probable aqueous (i.e., water-lain) origin. The LCS allows for grain size to be detected (down to the 100 micron, or better, level), as well as grain shape. Also, the intensity of the reflected signal can be related to differences in the reflectivity of the minerals present, enabling different mineral constituents to be identified.

Structural Rock Face Analysis - A Terrestrial Application: The LCS technology was demonstrated in an underground mining environment at the International Nickel Company (INCO) Research Mine in Sudbury, Ontario, in November 2001 [2]. For this project, a tripod mounted, air cooled version of the LCS was used to acquire images of a drift and a "cut & fill". The 3D images and models derived from LCS data allowed a quantitative evaluation of the orientation and spacing of different sets of in-situ joints. This structural information is crucial when planning tunnel support. The project also demonstrated that the LCS images can be registered to a common coordinate frame to generate a precise 3D model of an area of the mine for future studies. This is particularly important if the rock faces later become inaccessible because they are covered with cement for support. In another potential application, images before and after blasting could be compared to measure the impact of blasting on the size and shape of the different rock blocks, to predict fragmentation and to tune blasting models.

Robotic Exploration: Grain shape and overall rock textures and structures will allow for rock classification in terms of the igneous, metamorphic or sedimentary processes of their origin. Further research will be aimed at defining broad rock types (e.g., basalt, granite, sandstone, gneiss etc.). This type of information is critical for exploration of unknown terrains on Earth and other planets. It can be obtained at standoff ranges up to 5m in certain cases. With typical planetary exploration progress measured in meters per day this means that the LCS has the potential to provide accurate classification of potential samples at distances that represent an entire day's travel for the sampling vehicle. The current space-qualified design will be developed, miniaturized and adapted (e.g., for the Martian environment) so that it can be carried on a small rover. The LCS will be used for ranging, and to aid in local rover navigation, but also for autonomously classifying dust, soil, and rock. These preliminary observations will be important for site selection and initial sample characterization prior to sampling/coring. It will also assist in selection of representative samples for subsequent more elaborate mineralogical, chemical or isotopic analysis.

Rock Sample Images*:* For planetary exploration, the LCS sensor could be mounted on a rover. Using the LCS, the rover scans and identifies several potential sample sites. A possible scenario is that the rover has discovered a landscape strewn with blocks of rock of varied provenance. The first task is to collect LCS images of the blocks. This rapid procedure not only accurately positions the blocks with respect to the rover, the images are sufficiently detailed that some of the rocks can be identified as to their probable type and origin. When the images are collected, and compared with available images of igneous, sedimentary and metamorphic Earth rocks, it is immediately clear the rover has discovered an important area strewn with different samples that yield planetological information.

Building Closed 3D Volumetric Models:

Meteorite: Closed 3D volumetric models of several geological objects, including the St-Robert chondritic meteorite [3], have been built from LCS data. The first step in analysis of the 3D surface data is the production of point cloud data. The point cloud data set consists of the directly measured 3D array of points prior to any interpolation or surface reconstruction. Point cloud data can be manually edited to remove edge effects and clutter. Several point clouds can be used to build surface maps of large areas. In fact, the LCS data acquired from different view points but with an overlapping region can be aligned, and combined in 3D space, using an Iterative Closest Point (ICP) algorithm. This process is entirely data-dependent and does not require that the location of the camera or the object be known. Adjacent views are added one by one until a closed volumetric model is built. The visual perception of the models can be further enhanced by overlaying the LCS measured intensities or by combining both measured intensities and light rendering effects .

Other Objects: In a completely different application, the model building process has been applied to LCS scans of reduced- and full-scale vehicles to populate an automatic target recognition (ATR) database [4]. In the example of a reduced-scale Hummer vehicle, the very detailed final 3D model was built from 18 aligned views and its surface included 280,000 polygons.

Potential: Clearly the transportability of the LCS (even before miniaturization for robotic and/or planetary applications) means that it already has many potential field and laboratory uses. Sample and object-based research in many areas of science and technology often requires archival, time-sensitive or other documentation without significantly disturbing the "evidence" or subjecting objects to manipulation that may damage them. 3D LCS models can be manipulated and viewed in great detail without disturbing the original object beyond acquiring the point cloud data. Whether objects fit together can be investigated without handling them. Surface features can be detailed down to 100 microns and viewed from different perspectives. The ability to build closed 3D volumetric models means that densities of fragile or reactive materials can be calculated by weighing them and imaging them. Closed 3D volumetric models can be used to reproduce casts of original objects in different materials, or real-weight replicas. They are valuable additions to collections databases. LCS images and models of valuable objects can be shared amongst investigators, without compromising the real objects' security and integrity.

References:

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