EXOMARS: PRE-LAUNCH PANCAM MODELING AND ACCURACY ASSESSMENT. R. Li[1], D. Li[1], L. Lin[1], X. Meng[1], K. Di[1], G. Paar[2], A. Coates[3], J. P. Muller[3], A. Griffiths[3], and J. Oberst[4], D. P. Barnes[5]. [1]Mapping and GIS Laboratory, CEGE, The Ohio State University, 470 Hitchcock Hall, 2070 Neil Ave., Columbus, OH 43210-1275, USA, li.282@osu,edu; [2]Institute for Information and Communication Technologies, Joanneum Research, Graz, Austria; [3]Mullard Space Science Laboratory, Dept. of Space and Climate Physics, University College London, London, UK; [4]Institute of Planetary Research, German Aerospace Center (DLR), Berlin, Germany; [5]Space Robotics Group, Dept. of Computer Science, Aberystwyth University, UK.

Introduction: The goal of this research is pre-launch quantitative analysis of the mapping and localization accuracy of the Panoramic Camera (PanCam) vision system designed to be carried onboard the European Space Agency (ESA) ExoMars rover mission for launch in 2018. This ExoMars rover is designed to travel kilometers across the Martian surface [1], thus high-precision rover localization and topographic mapping will be important for traverse path planning, safe planetary surface operations and accurate framing of scientific observations within a global spatial context. For such purposes, ExoMars PanCam imagery will be integrated into an image network to provide precision data for photogrammetric algorithms used to localize the rover and generate 3-D mapping products.

This paper presents results from both theoretical and experimental analysis of the attainable mapping and localization accuracy of the ExoMars PanCam system under the latest ESA specifications [2]. The ExoMars PanCam system consists of two Wide-Angle Cameras (WACs) and one High-Resolution Camera (HRC). Each WAC has a larger field of view (FOV) but a smaller focal length than the HRC. A rigorous mathematical model has been developed to estimate mapping and localization accuracy of the WAC stereo vision system based on photogrammetric principles and error propagation theory. To take advantage of the much longer coverage of the HRC, data captured by HRC has been integrated into this rover localization method to evaluate its ability to enhance localization results.

In order to assess the rover localization accuracy using the ExoMars PanCam prototype, and to evaluate results of the theoretical error analysis, a field experiment was conducted on the island of Tenerife, Spain in September 2011 [3]. A 120-m traverse across five sites was performed using the Aberystwyth University PanCam Emulator (AUPE) mounted on the Astrium Bridget Rover (Fig. 1). At each site along the rover traverse, a series of panoramic images was acquired by the PanCam stereo WACs at different tilt angles. These panoramic images were further linked into an image network based on a number of high-quality, well-distributed features identified across adjacent sites. Then, incremental bundle adjustment (BA) was performed to obtain accurate rover positions along the traverse [4]. Finally, this experimental localization accuracy was compared to the expected positions derived from the developed theoretical rover localization error analysis model.

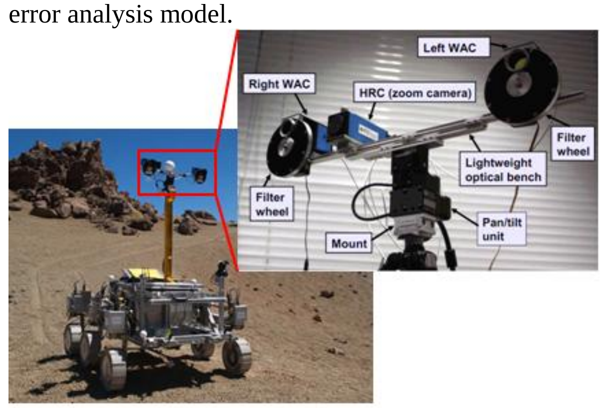

Figure 1. Astrium Bridget Rover carrying the AUPE [3].

Theorectical Model for Rover Localization Error Analysis: Theoretical analysis of the attainable level of accuracy is based on a two-site rover localization model as rover operations are usually performed incrementally, sol by sol. In this model, the location of the rover at the first site is fixed. The location at the second site is determined by identification of matching features or tie points between these two sites and a BA. It is assumed that the only possible sources of error are the measurements of the image coordinates of these features. Based on stereo triangulation and intersection equations, errors in the spatial coordinates of the feature points are determined from errors in the image coordinates of the features. As the rover would be at the second site looking backward to view these feature points, the space resection method is used to triangulate the position of the rover at the second site. As a result, feature-measurement errors can be propagated into the rover position at the second site.

Evenly distributed features in the middle of two adjacent sites, in general, produce higher localization accuracy. The distribution of features can be defined in terms of the convergence angle (Fig. 2), i.e., the maximum forward- or backward-looking angle that covers the entire area of identified features [5]. It is critical to obtain the optimal convergence angle at which the positional error of the rover at the end of a fixed traverse segment can be minimized.

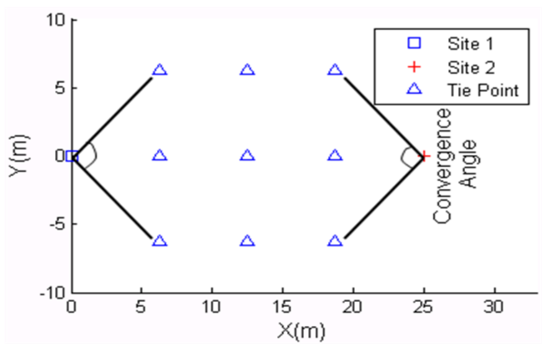

Figure 2. The features/tie points distribution in terms of convergence angle of a two-site traverse [5].

Figure 3 shows the results of how the relative rover localization error changes as the convergence angle of nine tie points was varied from 50 ° to 120 °. The traverse segment length was maintained at 25 m, and the relative rover localization error is defined as the ratio of the position error at the end of the traverse segment to the length of the segment. As can be seen on Figure 3, the optimal convergence angle for a total number of nine tie points is approx. 90 ° for ExoMars PanCam stereo WACs. According to our experiences on Mars Exploration Rover (MER) mission operations, the practical range of the convergence angle used is from 70 °to 110 °.

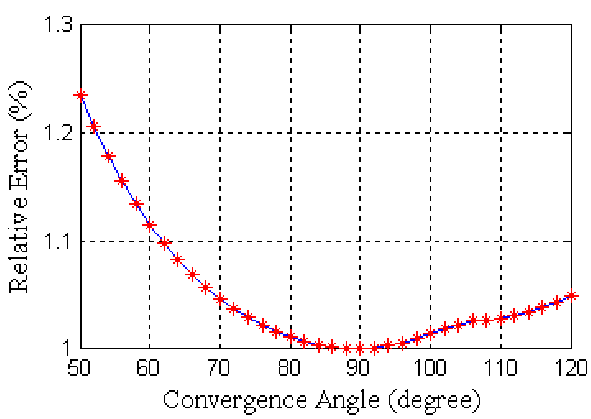

Figure 3. Relative localization error vs. convergence angle

Applying the error propagation rule, the two-site scenario can be extended to cover an entire traverse having multiple sites [5]. Therefore, we designed a 120-m traverse consisting of four equal traverse segments, and we expect the rover can achieve an overall relative localization accuracy of 0.5% ($4^{1/2}/4$ *1%) under the constraints of nine tie points and the optimal convergence angle of 90 ° for each traverse segment.

Field Expriment Results: This field experiment was conducted at Llano de Ucanca on Tenerife island. This test site is a relatively flat area surrounded by hills. The surface consists of volcanic sand, pebbles and occasional rocky outcrops, a condition similar to that encountered on Mars by the MER rovers. In this experiment, the rover traversed four segments (30 m each determined by laser tape) along a linear traverse for a total traverse of 120 m.

At each site along the traverse, several panoramas were acquired by the AUPE stereo WACs at different tilt angles. Data from the AUPE HRC camera is still being processed; it will be available later. After applying epipolar geometry constraints to the PanCam images to produce linearized images, nine high-quality and well-distributed features were selected for each traverse segment from the linearized images. Simulating the MER rover localization scenario during operations, an incremental BA was conducted to obtain accurate rover positions during a traverse sequence. Finally, rover localization errors were calculated for the four consecutive traverse segments (Fig. 4).

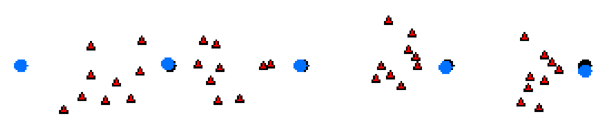

Figure 4. Rover sites along the traverse (blue dots) and the features or tie points (red triangles). The black dots represent rover reference positions measured using standard GPS, while the overlaid blue dots represent the same rover positions as calculated by the BA. The measurement error of rover position is within 4 cm due to GPS placement.

Although the terrain features were carefully selected and the convergence angle was closely constrained to 90 °, it was difficult to maintain an even feature distribution in the practical fied experiment. Thus the relative localization error over a 120-m traverse was found to be 1.2 percent, which is not far from the ideal theretical analysis result of 0.5 percent.

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