AUTOMATED GLOBAL FEATURE ANALYZER (AGFA) FOR THE INTELLIGENT AND AUTONOMOUS ROBOTIC EXPLORATION OF THE SOLAR SYSTEM

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Introduction: A multinational lunar and Mars exploration program is currently underway. Future missions involve multiple spacecraft, which are planned to orbit or land on the Moon and on Mars within the next decade. Varied instrumentation on these spacecraft have been generating huge datasets, and will generate unprecedented amounts of data in the future. In addition, as more missions spread out into the Solar System (e.g., Venus, Mercury, Titan, Pluto, asteroids and comets), other potential problems arise, including communication time lags and bottlenecks as missions compete for downlink and uplink time, straining deep-space communications. These and other potential problems using traditional onboard software make it infeasible and cost-prohibitive to explore remotely large expanses of planetary surfaces independent of Earth control.

A traditional rover mission, for example, collects information at each stop along its planned traverse. This scenario is time and personnel intensive, and thus extremely costly. Just as significant, vital information may be bypassed along the traverse path. To construct a coherent history of what has transpired in the area of interest over geologic time, the reconnaissance field geologist moves from one patch of rock materials (or outcrops) to another over varying geological terrains. While tracking location and considering regional information previously compiled from published geological, topographic, geophysical, and hydrological information, the field geologist gains a local and regional perspective of the geological, hydrological, environmental, and climatic histories of a chosen site by gathering essential field data en route. A comprehensive understanding of the geology, hydrology, environment, and climate by the field geologist can be achieved by coupling regional information with high-resolution information carefully compiled while covering large expanses.

Traditional missions will have to be replaced by fundamentally new planetary exploration paradigms, such as *Tier-Scalable Reconnaissance*©, originated by Fink et al. [1-7], to allow for distributed, science-driven, and less constrained reconnaissance of prime locations on Mars, the Moon, Titan, Venus, etc. For future missions to be economical, science effective, and communication efficient, a high degree of operational autonomy is required [5], such as:

- Automatic mapping of operational areas from different vantages (e.g., space, aerial, or ground);
- Automatic feature extraction and target/region-of-interest/anomaly identification;
- Automatic target prioritization for follow-up or close-up (in-situ) examination;
- Subsequent automatic, targeted deployment and navigation/relocation of agents/sensors (e.g., to follow up on transient events).

In place of astronaut geologists, the initial exploration of Mars, Titan, and other planetary bodies will be conducted by robotic spacecraft. Therefore, training and equipping a robotic craft with the sensory and cognitive capabilities of a planetary/field geologist to form a *science craft* is a necessary prerequisite. Numerous steps are necessary for such a science craft to be able to automatically map, analyze, and characterize an operational area, and effectively formulate working hypotheses. Its main benefit will be the potentially increased science return during the respective mission lifetime and thus greater cost effectiveness.

We report on the continued development of the integrated software system *AGFA*©*: Automated Global Feature Analyzer*© [9], originated by Fink at Caltech and his collaborators in 2001 (formerly *Automated Geologic Field Analyzer*© [8, 9]).

Methods & Technical Implementation: AGFA performs automated target and anomaly identification and characterization through segmentation, providing for feature extraction, classification, and target prioritization within mapped operational areas at different length scales and resolutions, depending on the vantage (e.g., spaceborne, airborne, or surface/subsurface). Figure 1 shows the functional steps of AGFA and how they build on each other (mathematical details of AGFA provided elsewhere). In one embodiment of AGFA we focus on the *geologic* classification of operational areas, such as extraterrestrial geologic field sites encountered by a planetary rover or lander.

AGFA comprehensively extracts features, such as target shape, size, color, albedo, texture, vesicularity, angularity, eccentricity, compactness, extent, and thereby obtains *feature vectors* for all identified targets/rocks within the imaged operational area (Fig. 2). These feature vectors are subsequently used by AGFA to summarize the mapped operational area numerically, to classify targets/rocks, and to automatically flag anomalies, i.e., targets that exhibit sufficient anomalous character within the feature space. This is done in an objective, i.e., exclusively feature-driven and thus unbiased manner as opposed to a biased, human hypothesis-driven manner. In contrast to Artificial Intelligence (AI) schemes (e.g., [10, 11]), AGFA does not depend on expert-defined rule sets, but operates instead within the classification-inherent feature space itself. In addition, AGFA automatically prioritizes targets for followup investigation through advanced prioritization frameworks [12].

Discussion & Outlook: The integrated software system AGFA is a first-of-a-kind approach towards a fully automated (i.e., no human-in-the-loop) and comprehensive characterization of an operational area. Employed by a planetary explorer such as an orbiter, balloon, or rover/lander, AGFA is an extensible analysis and classification framework, not limited to the currently implemented methods.

An additional strength of AGFA is the fact that, when embedded into tier-scalable reconnaissance architectures [1-7], it enables, for the first time, intelligent, autonomous, and targeted robotic exploration of remote planetary surfaces not only from the ground but from the air and space as well. For example, aerial reconnaissance platforms on Mars, Titan, or Venus in addition to or in place of rovers could cover significantly larger surface areas in a much shorter time than previously possible [1-7].

Our goal is to eventually merge AGFA with other innovative tools for autonomous science analysis of geological field sites, including GIS-based multi-layer information, which includes published geological, topographic, geophysical, mineralogic, and hydrological data sets at local, regional, and global scales. This *Multi-Layer Information System (MLIS)* [1], containing geologic, structural, and erosional information, combined with AGFA capabilities could help unravel complex geologic histories at local, regional, and global scales that can be readily updated with information obtained from, e.g., future tier-scalable reconnaissance missions.

Although the current focus is mainly on geologic classification of operational areas, future embodiments of AGFA will address (1) geophysical, (2) geochemical, (3) (hyper-)spectral, and (4) biological classifications of operational areas for enhanced geologic and exobiological exploration.

AGFA is currently being tested aboard ground-based robotic platforms [4, 5] and will be tested in the near future aboard airborne platforms, such as helicopters and blimps, as part of the tier-scalable reconnaissance mission test bed at Caltech [4].

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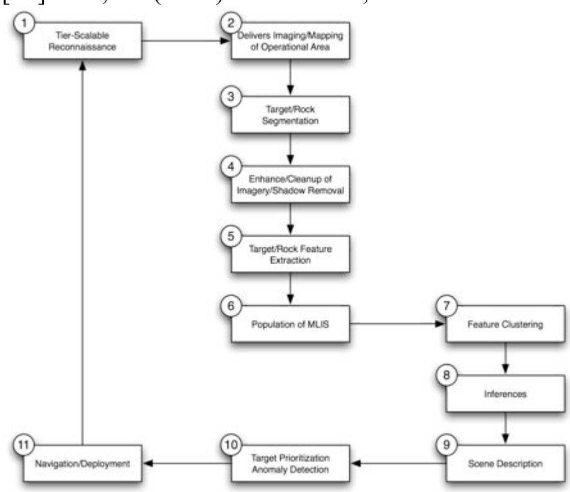

Fig. 1. AGFA operational diagram [8, 9].

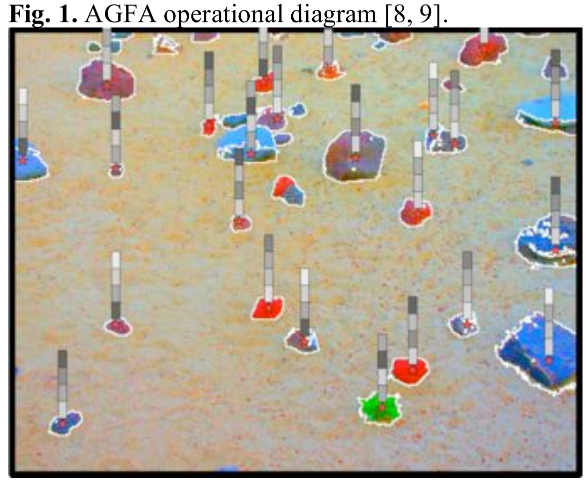

Fig. 2. Identified/segmented targets (here: rocks) within imaged operational area and their respective extracted feature vectors, derived by AGFA [8, 9].