ADAPTER-BASED MICROSCOPIC AND WIDE-ANGLE IMAGING CAPABILITY FOR DIGITAL CAMERAS FOR PLANETARY EXPLORATION AND ASTROBIOLOGY

W. Fink[1], W.C. Mahaney[2], K.R. Kuhlman[3], [1]California Institute of Technology, *Visual and Autonomous Exploration Systems Research Laboratory*, Division of Physics, Mathematics and Astronomy, Mail Code 103-33, Pasadena, CA 91125, wfink@autonomy.caltech.edu, Website: http://autonomy.caltech.edu, [2]Geomorphology and Pedology Laboratory, York University, Canada, arkose@rogers.com, [3]Planetary Science Institute, Tucson, AZ, kim@psi.edu.

Introduction: A fundamentally new scientific mission concept, termed *tier-scalable reconnaissance*, for (remote) planetary atmospheric, surface, and subsurface exploration recently has been devised (e.g., [1-3]) that is aimed at replacing the engineering and safety constrained mission designs of the past. The "tier-scalable" paradigm integrates multi-tier (orbit⇔atmosphere⇔surface/subsurface) and multi-agent (orbiter(s)⇔blimps⇔ground agents/sensors) hierarchical mission architectures [1-3], not only introducing mission redundancy and safety, but enabling and optimizing intelligent, unconstrained, and distributed science-driven exploration on a global, regional, and local scale.

To support such tier-scalable reconnaissance mission architectures, requires not only a high level of operation autonomy (e.g., [4-7]) but also a new class of multi-purpose and reconfigurable instruments/sensors (e.g., intelligently reconfigurable snapshot hyperspectral imager [8]).

Digital cameras (Fig. 1a) have both optical and digital (i.e., interpolation) zooming capabilities (mostly tele-zoom). Most digital cameras possess a macro-mode for taking images up-close, usually from a distance of around 20cm from the object. Furthermore, most commercial-of-the-shelf (COTS) digital cameras are in the megapixel class (usually >5MegaPixel). Nevertheless, the vast amount of magnification attainable with digital cameras is governed by two factors: (1) the native resolution of the CCD/CMOS-chip of the camera, and (2) the distance between camera lens and object to be imaged (focal length).

For the purpose of introducing microscope-like capabilities to a digital camera, both the tele-zoom, and the macro-mode are insufficient, because the object cannot be magnified enough by either placing the camera close enough to the object and/or by magnifying the object with a zoom. Therefore, the goals are to reduce the focal distance and to increase the native resolution of the camera.

Methods: As a proof of concept, a digital camera with a microscope-like imaging capability has been devised and prototyped [9] (Fig. 1a). The prototype comprises a (5MegaPixel) digital camera that has been modified, i.e., equipped with custom adapter, custom macro-lens, illumination assembly, and foam spacer.

Results: With this assembly it is currently possible to place the (COTS) 5MP camera within a focal distance of 1-5cm from the object, and to obtain further magnified images with the optical zoom, or in addition the digital zoom, fully engaged.

Figure 1c-h shows several imaging examples that demonstrate the optical performance capabilities of the current prototype: With the optical zoom engaged the prototype currently achieves a resolution of about 5μm per pixel, and with the additional digital zoom a resolution of about 1.2μm per pixel across a 2560 (h) x 1920 (v) pixel (5MP) image.

Higher resolutions/magnifications can be obtained using a larger CCD/CMOS-chip and/or different lens systems attached to the adapter. This adapter assembly is generic and can be custom-tailored to a multitude of digital cameras. It can be mounted on the protruding lens of a camera or to the non-moving body of the camera around the lens, leaving space inside for the actual lens to protrude and to perform (auto-)focusing and zooming operations. The adapter may also be mounted magnetically, etc. Once the adapter is in place, almost arbitrary lens systems can be mounted to the adapter in addition to the built-in optics of the camera. Figure 1b shows an extreme wide-angle (fisheye) image, taken with the same digital camera using a wide-angle lens. (The warping can be eliminated by using a rectilinear wide-angle lens.)

If imaging an object close-up (e.g., planetary soil or rock), a spacer can be mounted around the adapter and the magnifying lens assembly to shield the optics from ambient light (e.g., for the detection of chemo-luminescence). Inside that spacer well-defined artificial illumination sources, such as LEDs, can be placed that either directly or in a diffuse, indirect manner illuminate the object. These illumination sources may comprise but are not limited to UV, for potentially evoking fluorescence, and polarized light. If the object exhibits disturbing glare due to the illumination, polarized filters can be used in front of the lens to filter out the glare.

Potential Applications: This adapter-based microscope-like capability for digital cameras has a wide range of applications: (martian) soil (pedology) and sedimentary rock examinations, rock examination, astrobiology, planetary mapping, etc.

Close-up examination of rock and soil surfaces: Geological sections could be studied for evidence of weathering - chemical alterations that might indicate the presence of weathering mantles, rock varnish and/or true paleosols [10, 11] resulting either from interaction of the lithosphere with the ancient martian atmosphere or from ground water fluxes. Photographic evidence might warrant close-up microscopic examination of particular horizons, especially those with weathering rinds that might contain extant or fossil microbes [10-12]. High-magnification imaging may allow measurement of particle size and shape distributions of soils and sedimentary rock cross-sections, providing valuable information about their deposition.

Close-up examination of biomediated films: The presence of biofilms and bioforms similar to samples studied on Earth [10] may be identifiable with this microscopic capability. If found on the martian surface such forms could potentially be imaged with this equipment.

Close-up examination of rock varnish: Rock varnish has been suggested to exist on the martian surface based on images returned by landed missions [13]. Definitive identification of rock varnish on Mars will require the highest state of magnification possible to detect micrometer-scale lamellate or botryoidal surfaces, which could be studied later on with Scanning Electron Microscopy - Energy Dispersive Spectroscopy (SEM-EDS) and Transmission Electron Microscopy (TEM) [11,14, 15]. Identification will also require high-resolution imaging of a cross-section of the coating in question. This microscope may be capable of preliminary identification of textures associated with rock varnish, allowing for further investigation of possible astrobiological implications that could provide new information on Noachian paleoenvironments and relative scales of biological evolution on Mars relative to Earth in its formative stages. High magnification fluorescence imaging of purported rock varnishes on Mars may also reveal microcolonial fungi as documented on Earth [15-17].

Outlook: We have demonstrated an adapter-based capability to (re)use the same digital camera for microscopic as well as wide-field imaging. It is envisioned to be deployed on rovers, landers, and airborne platforms such as blimps, that may have the capability of remote and in-situ sensing (especially on Mars and Titan). This type of multi-purpose/reconfigurable instrument may render future missions more cost-effective, and, together with automated feature extraction and science goal prioritization software packages [4, 5], is ideally suited for tier-scalable reconnaissance missions [1-3].

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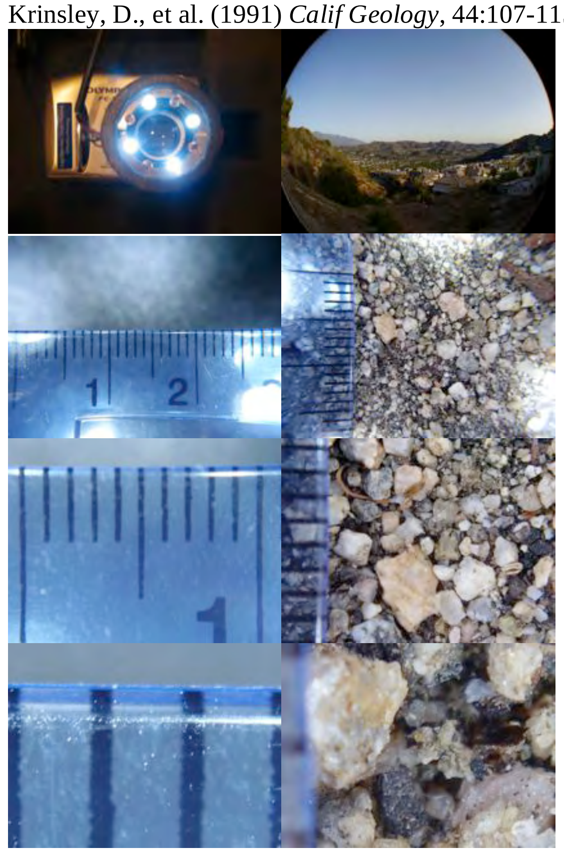

Fig. 1. (a) modified digital camera with microscopic imaging capability and illumination assembly; (b) wide-angle (fisheye) imaging capability; (c, d) microscopic imaging of soil patch w/o zoom, (e, f) w/optical zoom (5μm per pixel), (g, h) w/additional digital zoom (1.2μm per pixel). All images are 2560 x 1920 pixel (5MP).