PLANETARY-PROTOTYPE DRILLING AUTOMATION AT A MARS-ANALOG SITE. B. Glass[1], H. Cannon[1], S. Hanagud[2], P. Lee[3], G. Paulsen[4], K. Zacny[4], [1]NASA Ames Research Center, Moffett Field, CA 94305, USA, Email: brian.glass@nasa.gov, [2]Georgia Institute of Technology, Atlanta, GA 30332, USA, [3]SETI Institute, Mountain View, CA 94305, USA, [4]Honeybee Robotics, 460 West 34th Street, New York, NY 10001, USA.

Introduction: The search for evidence of organics on Mars, and possible lunar resources, drives the need for the eventual acquisition of subsurface core samples. The Drilling Automation for Mars Exploration (DAME) project's purpose was to develop and field-test drilling automation and robotics technologies for projected use in missions in the 2011-15 period [1]. Figure 1 shows a lightweight, planetary-prototype drill, in DAME summer Arctic field testing [2]. DAME included control of the drilling hardware, and state estimation of both the hardware and the lithography being drilled and the state of the hole. A sister drill was constructed for the MARTE project and demonstrated automated core handling and string changeout in 2003-05 field tests [3,4]. DAME focused instead on the problem of drill control while actively drilling – "making hole" while not getting stuck.

Fig. 1. DAME planetary drill prototype at Devon Island analog test site (Haughton Crater).

The DAME project's objectives [5] were therefore to first conduct manual low-power dry drilling under relevant conditions, both in the laboratory and at an analog site, in order to discover and model the behavior of the drill under a range of operating conditions including problems and faults. Then in the second year, to take initial software controls and diagnostic models and place them in observation (but not control) of the drill in the same drilling locations and conditions. Then with the knowledge gained from these tests, to refine the automation, close the control and operations loop and in a third year to test hands-off drilling in the same drilling locations and conditions.

Approach: How do humans accomplish drilling? Roughnecks and engineers use a priori analysis of drilling areas to build models of expected strata and hence drilling environments at varying depths. And use a body of gained experience to assess logs and drilling state values. The drill shaft is a source of tactile and audible feedback, as its vibrations change. So to address drilling automation, DAME designers took these same approaches (model-based, heuristic, and vibration perception) as a starting point.

The DAME approach is to apply three types of automation:

(a) real-time limit-checking and safing;

(b) near-real-time vibration measurement and fast frequency-domain pattern-matching using a neural net; and,

(c) monitoring system state parameters and inferring system state using both rule-based and model based diagnostic techniques.

DAME had one ongoing, natural input source of drill excitation -- the normal rotation of the drill string or the auger tube. A single type of noncontact sensor – two laser vibrometers (LDV) -- were used in DAME, employing speckle interferometry along with with real-time Fourier transforms over moving measurement windows. These resulted in identified natural frequencies and mode shapes of the drill shaft, which in turn became inputs to a neural network to perceive and identify different drilling and fault conditions.

Field Tests: For DAME, a planetary-analog drilling site was needed – someplace with subsurface ice (as at the Martian higher latitudes) and the broken, depth-graded textures similar to impact regolith. Similar morphology, such as a crater site, was considered a plus. The Haughton-Mars Project operates a research station in the Canadian Arctic adjacent to Haughton Crater, on Devon Island, Nunavut at 75.2N, 89.7W, jointly supported by NASA and the Canadian Space Agency. The Haughton Crater Research Station (HCRS) base provides seasonal logistical support for up to 40 researchers and staff working in or around the 22-km wide Haughton Crater impact site during summer months.

Results: The DAME drill and automation software was deployed to the HCRS for its third season of testing from 15-28 July 2006. The drilling site was chosen on a massive breccia deposit located inside the northwest crater rim [6]. A large 5m-diameter dome tent covered the drill and support equipment. A portable generator provided power, although the drill itself was constrained to use no more than 150W peak. A communications relay to HCRS base camp provided data access back to NASA Ames and JPL for a later live field demonstration on 27 July.

All DAME 2006 test goals were completed successfully. All six known primary drill hardware faults were encountered naturally in the course of drilling, none had to be artificially induced, and the last of the six occurred on 24 July, a week into drilling. Five of the six faults were correctly identified, repeatedly, corrective actions were taken by the automation software and drill, and the drilling continued. The lone fault that was routinely mis-identified was Auger Choking – there was not sufficient torque to distinguish it from Bit Jamming, in large part due to parasitic drag because of incidental reaming along the vertical length of the auger shaft. Figure 2 shows one of the faults (hard material) detected and an adjustment done autonomously while drilling.

A total of 44 hours of autonomous, hands-off drilling was accomplished over eight days. And a total depth of 3.2m was reached, into the frozen breccia, with cores obtained. All three diagnostic methods (rule-based, model-based, and vibration-neural-net) were used together and demonstrated robust, reliable monitoring and analysis of the drill and drilling operations. False-positives were less than 10%. The vibration-analytical neural net was able to detect changes from shifts in natural frequencies and mode shapes. Figure 3 compares nominal frequencies with a given faulted case (unexpected harder material).

Once all DAME field test goals had been met, a "bare" or "exposed" test was run on the evening of 27 July. This consisted of starting an automated drilling sequence, and then directing the human staff to leave the equipment completely unattended while having dinner several miles away at the HCRS base camp. Upon their return four hours later. the automated sequence was still going on and the DAME system had detected and successfully responded to a fault and continued.

Conclusions: The DAME project has developed hardware and software, complementary diagnostic approaches, and completed a series of field tests in a relevant environment, leading to drilling automation maturation suitable for consideration in future missions. Future work is needed to bring together the DAME drilling automation with the MARTE core handling and topside automation technologies as an integrated whole.

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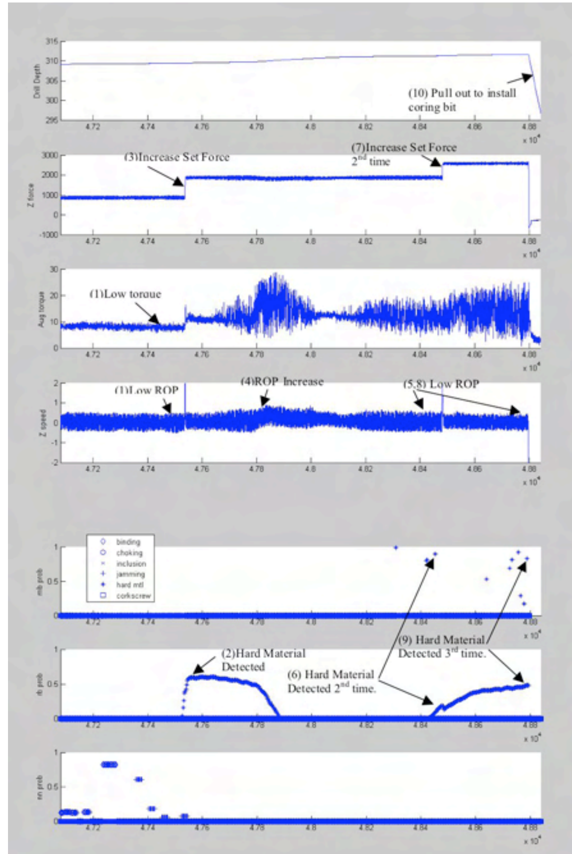

Fig. 2. Hard Material Detection and Drill Recovery.

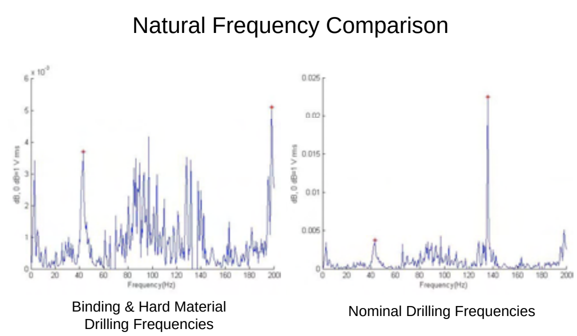

Fig. 3. Nominal vs. binding/hard material frequencies show shifts and amplitude changes that are detectable with a neural net.

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