DEVELOPMENT OF AUTONOMOUS DRILLS FOR PLANETARY EXPLORATION.

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Introduction: Direct subsurface sampling is the most fundamental technique for exploring unaltered in situ characteristics of any planetary subsurface [1]. For subsurface exploration below a few meters, it is evident that planetary drilling is necessary. However, complications due to limits in mass, manpower, and energy [2] mean terrestrial drills must become highly autonomous. Honeybee Robotics in partnership with NASA Ames Research Center, Los Alamos National Labs, Ion Optics, Inc., and NASA JPL has developed down-hole instrumentation to enable science driven autonomous drilling. This includes, but is not limited to, autonomous sampling, down hole scientific instruments, and drill diagnostics.

Two "sister" drills have been developed under the NASA Ames partnership as part of the Mars Analog Rio Tinto Experiment (MARTE) [3] and the Drilling Automation for Mars Exploration (DAME) [2] projects. Initial developments from these drills have resulted in the use of down-hole instruments for capturing samples and measuring and controlling various drill characteristics. Under the partnership with Los Alamos National Labs, Ion Optics, Inc., and NASA JPL, developments in the integration of neutron and infrared spectrometers into drill segments have been investigated. This research is part of the Mars Instrument Development Program (MIDP). Additionally, ongoing studies are investigating the use of implementing other instruments such as a microscopic imager, mechanical properties tester, thermal probe, and electrical properties tester for studying material properties below the surface.

Scientific Instrument Infrastructure (SII): Recent advances in sensor miniaturization have created new opportunities for scientific instrumentation in many situ environments. Honeybee Robotics has developed a Controller Area Network (CAN) based infrastructure to accommodate scientific instruments in its suite of deep drilling platforms. This infrastructure is comprised of a command and data handling network, a miniaturized data acquisition system, signal conditioning, node based NVRAM for data acquisition, a power distribution system, and communication protocols that allow new nodes to be added in real time. This platform allows integration of a wide range of instruments for real time scientific data gathering. Honeybee's modular drill segment approach allows a unique instrument to be installed into each segment of the drill stem. The SII is scalable in real time as the drill depth increases.

Each CAN Node has the capability of sending either a single packet of time critical data or buffering the input to the node at high sampling rates. Up to 2 Mbits of data can be sampled and stored into each node's nonvolatile FRAM. Each node is capable of sampling a single channel at rates of 25 kHz into a local buffer. The board has 4 analog channels, 2 pulse width measurement channels, and 2 real time interrupts. Scientific data is retained in flash memory if power is lost. This node will hold the data in memory until the network is ready to accept it.

Each node is comprised of two boards. The first is a communication and processing board. This board handles all control, data acquisition, memory, and communication. It connects to the user specific interface board for communication. The second board contains power and signal conditioning.

The processing board will be identical for every node in the system except for its node address. This board connects through a standard interface to the second board, which is designed to cater to the customer's instrument. This reduces design time and adapts to a suite of instruments.

Automation: Honeybee Robotics' down-hole instrumentation technology enables real-time decision making for autonomous drill control based directly on the subsurface environment. Intelligent algorithms are being developed at NASA Ames Research Center to make parametric drilling decisions such as desired weight on bit, penetration rate, and rotation rate. These decisions are made with a high level controller based on telemetry received from the drill actuators and down-hole sensors [2,4].

A fully robust planetary drill must have the capability to detect when specific failures have occurred or are imminent so it can take the appropriate actions to either avoid a failure or recover from a failure. The goal of the DAME project is to prove this functionality in the summer of 2006 during a field test in the Canadian High Arctic.

The DAME drill is outfitted with sensors located near the drill bit to measure the load on bit, torque on bit, bit temperature, and bit vibrations. Parameters measured at the surface include the torque and force used to auger the cut material and bit rotational speed and rate of penetration. With the sensor information available to the DAME drill, certain failure modes such as auger choking, auger jamming, and bit wear can be detected and avoided.

The MARTE drill utilizes a slightly different instrumentation package. The primary focus of this drill is to automate the collection and delivery of subsurface cores. Due to volume limitations near the drill bit, down-hole weight on bit, torque on bit, temperature, and vibration were not implemented. The science driven requirement for 27 mm diameter by 250 mm long cores drives the MARTE system design. Autonomous core break-off, retention, and delivery to the surface is accomplished via down-hole power and signal transmission for actuators embedded in the drill segments. Up to 9 power/data lines may be passed through the drill shaft to the borehole.

Functions such as adding and removing drill segments, breaking and capturing cores, and handing the core off to subsystems are all automated. The drill software is responsible for managing several states or behaviors (i.e. drill, string management, core break, core capture, etc.) during the drilling process. Tests performed near Rio Tinto, Spain in September 2005 demonstrated automation of the drill. During these tests, the MARTE drill was able to autonomously deliver a core to the surface as shown in Figure 1.

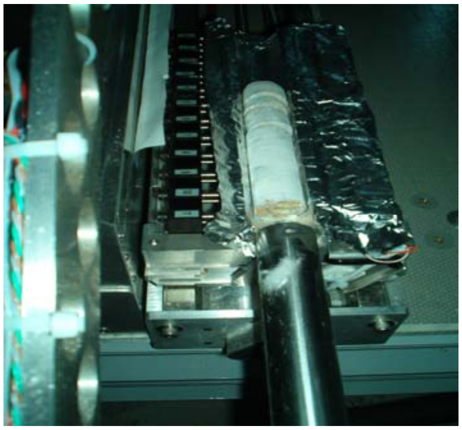

Figure 1: MARTE Core Delivery

Instrument Integration: In cooperation with the Jet Propulsion Laboratory and Ion Optics, Inc., Honeybee Robotics integrated an array of six different windows into a MARTE drill string. These windows, shown in Figure 2, enable an Infrared Spectrometer to view the borehole. Tests performed with the MARTE drill platform helped to determine which windows would be more resilient to wear, vibrations, and large temperature fluctuations associated with drilling.

Honeybee Robotics is also working in cooperation with Los Alamos National Labs. The goal of this cooperation is to integrate a Neutron Spectrometer into a drill segment as shown in Figure 2. Once implemented, it will be possible to take measurements in the borehole.

Data from drill telemetry is also helpful for material characterization. Bit Force, Bit Torque, Motor Torque, and Bit Depth are all collected in real time as shown in Figure 3. This data may be used to identify changes in stratigraphy to flag regions of scientific interest. If a flag is recorded, scientific data may be collected and sent to the surface. This data was collected with the DAME drill platform during tests performed on Devon Island in the Canadian Arctic in the summers of 2004 and 2005.

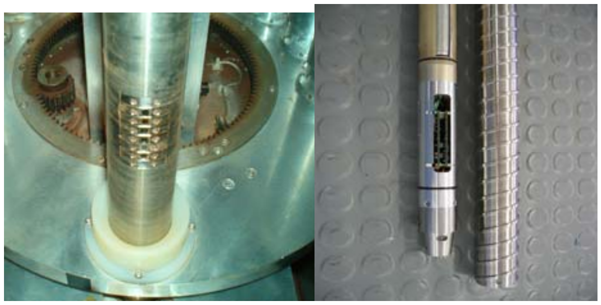

Figure 2: Infrared Spectrometer and Neutron Spectrometer Integration

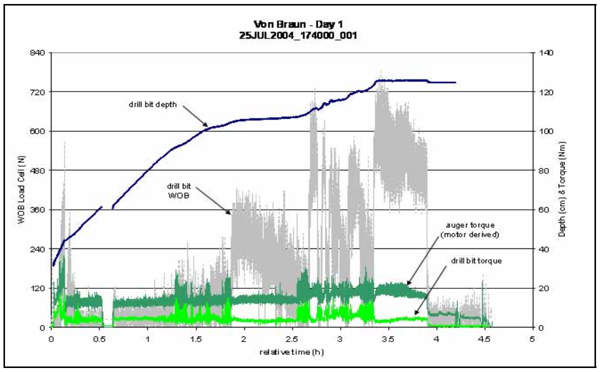

Figure 3: Drilling Parameters vs. Depth

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