AN INCHWORM DEEP DRILLING SYSTEM FOR KILOMETER SCALE SUBSURFACE EXPLORATION OF MARS (IDDS). S. P. Gorevan, (Honeybee Robotics, Inc., 204 Elizabeth Street, NY, NY 10012, gorevan@hbrobotics.com), K. Y. Kong, (Honeybee Robotics, Inc., 204 Elizabeth Street, NY, NY 10012, kykong@hbrobotics.com), T. M. Myrick, (Honeybee Robotics, Inc., 204 Elizabeth Street, NY, NY 10012, myrick@hbrobotics.com), P. W. Bartlett, (Honeybee Robotics, Inc., 204 Elizabeth Street, NY, NY 10012, bartlett@hbrobotics.com), S. Singh, (Honeybee Robotics, Inc., 204 Elizabeth Street, NY, NY 10012, sase@hbrobotics.com), S. Stroescu, (Honeybee Robotics, Inc., 204 Elizabeth Street, NY, NY 10012, sergiu@hbrobotics.com), Roopnarine, (Honeybee Robotics, Inc., 204 Elizabeth Street, NY, NY 10012, roop@hbrobotics.com), S. Rafeek, (Honeybee Robotics, Inc., 204 Elizabeth Street, NY, NY 10012, rafeek@hbrobotics.com)

Introduction: The Inchworm Deep Drilling System (IDDS) is a compact subsurface transport system capable of accessing regions deep below the surface of Mars. The concept is being developed at Honeybee Robotics to enable future subsurface science missions at depths on the order of one kilometer. The IDDS gets around the problems posed by tethers or umbilicals through the employment of drilling techniques that require no more power than that offered by a radioisotopic thermoelectric generator (RTG). The IDDS we propose requires no tether or umbilical of any kind. The tether free, self-powered and self-propelling device will be capable of burrowing to a specified depth and retrieving samples or of transporting instruments along with it for in-situ analysis. The IDDS also would be well suited for reaching greater depths on Mars or for subsurface exploration of Europa. The device's unique, inchworm-burrowing method appears capable of achieving the near-term depth requirement of one kilometer. In addition, it is foreseeable that the IDDS will be capable of autonomously drilling through soil, ice and rock down to tens of kilometers below the surface. Once deployed by a lander on the martian surface, the IDDS autonomously drills into the ground under it's own power. The inchworm motion of the device's two segments both walks it forward and provides the thrust necessary for drilling. Feet on each segment grip the walls of the hole. Flights along the body pass cuttings to the rear. Sampling and analysis take place once the proper depth is achieved, and since the burrowing method is independent of gravity, the IDDS can then return to the surface.

The Basic IDDS Conceptual Framework: The IDDS is largely a convergence of concepts from two previous devices designed and produced by Honeybee Robotics. The planetary surface burrowing mole concept extends our work on a tethered subsurface sampler effort conducted in 1993 for Dr. Paul Mahaffy at NASA GSFC [1]. And the inchworm burrowing method is a direct application of our work on the Welding & Inspection Steam Operations Robot (WISOR), a steam tunnel-walking robot provided for the Consolidated Edison Corp. of New York. The IDDS robot is between 10 and 15 centimeters in diameter and 1 meter in length. Two symmetrical segments comprise the IDDS, each with a drill bit and a set of three shoes. Figure 1 below shows a rendering of the concept.

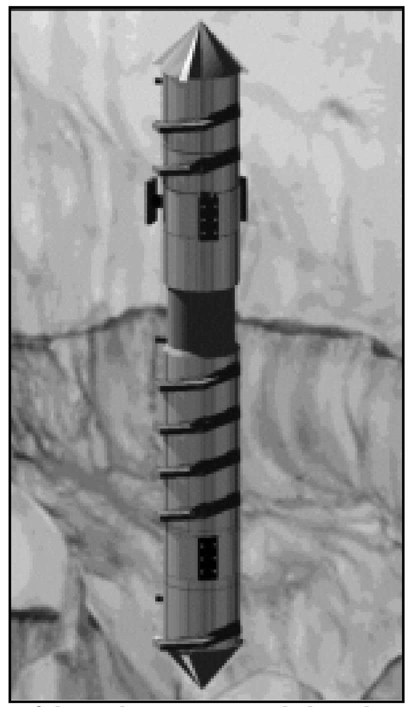

Figure 1: CAD Rendering of the IDDS concept

Power: As mentioned above, the IDDS utilizes a single RTG for electrical power. The high reliability, power density and output duration of RTGs state a strong case for their use in a kilometer-deep burrowing device. The IDDS dimensions are a practical forecast based on the current trend in RTG development.

Surface Deployment: The IDDS deploys at the surface in a similar method to the mole mentioned above that was developed for NASA GSFC. A cylindrical tube houses the IDDS while on the lander and the tube is positioned at the surface. To begin the burrowing process, the IDDS grips the inner walls of the tube and extends forward, into the soil. The IDDS continues to walk forward, eventually exiting the deployment tube and gripping only the walls of the hole it is creating.

Burrowing Method: The inchworm analogy that the IDDS employs allows it to burrow through soil independent of the magnitude or direction of gravity. A linear actuator connecting the aft segment to the fore segment of the IDDS contracts and expands the robot in length. Standard motors drive the fore and aft drill bits as well as each of the six feet (three fore and three aft). Thrust and torque for drilling and thrust for sliding the robot forward are achieved by anchoring the feet into the walls of the hole created. A similar method propels Honeybee Robotics' previous device, WISOR, mentioned above. WISOR walks through steam tunnels using two attached segments, each with feet that grip the inner walls of the pipe. Figure 2 shows one of the segments with its feet extended.

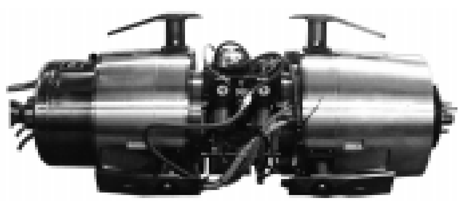

Figure 2: One segment of the Welding & Inspection Steam Operations Robot (WISOR)

Figure 3 below shows the stages of the IDDS burrowing process, beginning with step 1 on the left and continuing through to step 6 on the right. The figure demonstrates the walking cycle, which begins again in step 5.

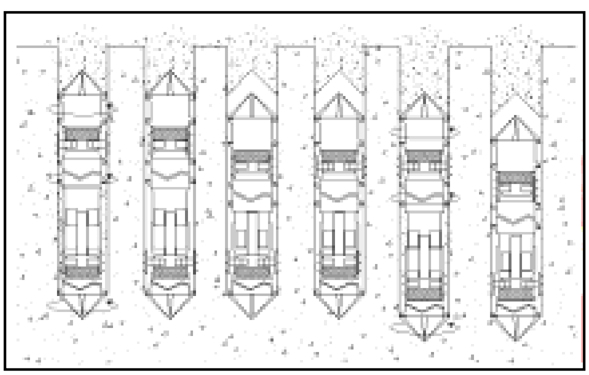

Figure 3: Schematic of the IDDS penetration process

Each of the six steps shown in Figure 3 is detailed below:

Step 1. The shoes on the aft section push into the borehole walls while the forward section extends forward slowly while spinning the forward drill bit, drilling deeper.

Step 2. The forward section shoes push into the borehole walls and the aft section shoes disengage.

Step 3. The IDDS contracts, pulling the aft section forward.

Step 4. The aft section shoes engage and the forward section shoes disengage.

Step 5. The cycle begins again as the IDDS extends while spinning the forward drill bit, drilling further.

Step 6. After engaging the forward shoes and disengaging the aft shoes, the IDDS contracts, pulling the aft section forward.

Drilling: Honeybee Robotics' extensive drill bit development for the Mini-Corer, a part of the Athena investigation, readily applies to the IDDS. The design of the IDDS drill bits will likely benefit from the company's present work in conjunction with DeBeers on both natural diamond and manufactured, polycrystalline diamond cutting teeth. Once the cutting teeth dislodge material and push it past the bits, rotating helical flights direct the cuttings along the body and to the rear of the robot. Since the cuttings would pack only loosely behind the robot, it is necessary for it to add a step in the burrowing process. This step consists of extending the rear section backward to compact the loose, freshly produced cuttings before moving on to a greater depth.

Accommodating Scientific Functions: Once the IDDS burrows to the depth specified, it can perform in-situ analysis as well as sample acquisition. With data and samples stored on board, the IDDS can reverse its burrowing process and return to the surface. Various in-situ observations and tests can be facilitated by the IDDS such as imaging and spectroscopy. Once samples are brought into the IDDS by the sample acquisition hardware, treatment of the samples such as baking for a GCMS would be feasible as well. Sample acquisition could consist of collecting loose cuttings or with the use of a Mini-Corer-type device, solid core samples. Sealed compartments contain the samples for their return to the surface.

References: [1] "A Tethered Subsurface Sample Acquisition System" performed for NASA Goddard Space Flight Center #NAS5-30894. Period of performance: April-November 1993.