# Auto-Gopher-2 (AG2) – Autonomous wireline rotary piezo-percussive drill for deep excavation

Yoseph Bar-Cohen, Mircea Badescu, Stewart Sherrit, Xiaoqi Bao, Hyeong Jae Lee, Shannon Jackson and Brandon Metz
Jet Propulsion Laboratory, California Institute of Technology, (MS 67-119), 4800 Oak Grove Drive, Pasadena, CA 91109,
Phone 818-354-2610, yosi@jpl.nasa.gov, web: http://ndeaa.jpl.nasa.gov

and

Kris Zacny, Bolek Mellerowicz, Daniel Kim, Gale L Paulsen
Honeybee Robotics Spacecraft Mechanisms Corporation, Pasadena, CA

- In order to reach great depths on the moon for human settlement, In-Situ Resource Utilization (ISRU) and construction of infrastructure applications will require effective drilling mechanisms.
- The required drill has to meet mass, volume and energy consumption constraints and conventional technologies are limited in meeting them.
- To address the related challenges, a deep drill, called Auto-Gopher-2 has been developed jointly by the JPL's NDEAA laboratory and Honeybee Robotics Ltd.
- The Auto-Gopher-2 is a wireline rotary piezo-percussive drill that combines breaking formations by hammering using a piezoelectric actuator and removing and collecting the cuttings by rotating a fluted bit.
- The hammering is produced by the Ultrasonic/Sonic Drill/Corer (USDC) mechanism that has been developed by the JPL team as an adaptable tool for many drilling and coring applications.
- The USDC uses an intermediate free-flying mass to convert high frequency vibrations of a piezoelectric transducer horn tip into lower frequency higher impact energy hammering of the drill bit.
- The USDC concept was used in a previous task to develop an Ultrasonic/Sonic Ice Gopher and then integrated into a rotary hammer device to develop the Auto-Gopher-1.
- The lessons learned from these developments were implemented into the development of the Auto-Gopher-2, an autonomous deep wireline drill with integrated cuttings management and drive electronics.
- Subsystems of this wireline drill were developed in parallel at JPL and Honeybee Robotics Ltd.
- The AG2 system was field tested by drilling in a consolidated gypsum formation and reached a depth of 7.52 meters.

Test of the ice-Gopher in Antarctica

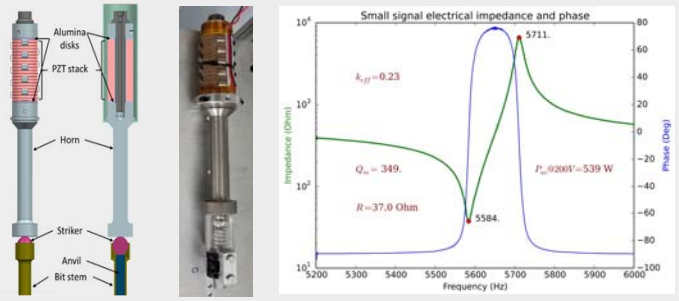
The gopher at 176cm deep in Lake Vida

Lake Vida test site

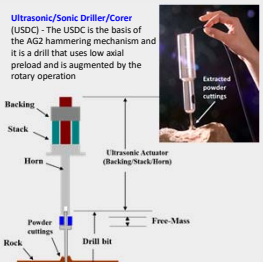
Field test of the Auto-Gopher-1

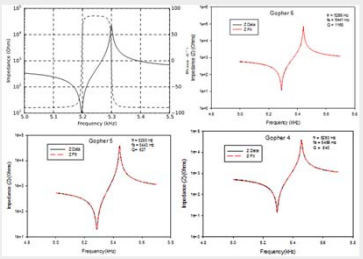
- 32 cores were extracted from a depth of 3.07 meter
- The field trip was performed over three days in November 2012

Auto-Gopher-2 - Transducer Development

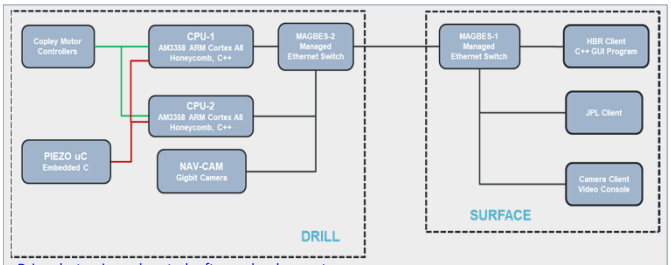



Design, components, first fabricated prototype, impedance spectra



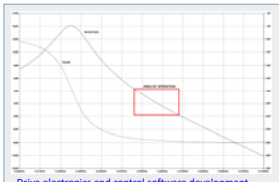



Impedance spectra of fabricated piezoelectric transducers




Drive electronics and control software development

- Power bus and communication through the umbilical cable
- All subsystems have local drive electronics and communication with the rest of the system and surface
- Developed separately then integrated into the system



Drive electronics and control software development

- Predefined drive voltage
- Select the drive frequency to control the current and power level

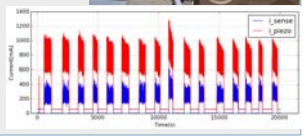
Laboratory testing

The laboratory setup with drill bit, test limestone block and a close up of the cable winch.

- Soft – 25MPa Cordova Crème - used to test subsystems interaction
- Hard – 40MPa Indiana Limestone – closer to the field site strength and cryogenic ice – used to verify performance

Field Test

- Transducer average current 0.85A (red) for a power of 68W (duty cycle, AC signal, phase difference)
- Supply current (blue) - (280V DC)




Field testing

- Borrego Springs gypsum quarry (US Gypsum Company facility)
- Average rock strength: 39MPa
- Input parameters: Sweep Current 1000mA; Fuse Current 1500mA; Cycle Time ON 2 sec; Cycle Time OFF 1 sec (Duty Cycle 66%).

## Conclusions and future work

- With the development of Auto-Gopher-2, we demonstrated a scalable technology that will make deep drilling possible with current launch vehicles, power sources, and entry descent and landing (EDL) systems.
  - Power < 500 W
  - Mass 65 kg
  - Length 3.7m
  - Flight like umbilical cable
  - Drilled 7.52m, more than twice the drill's total length
- Yet to be solved/improved
  - Reduce size (length) and mass
  - Automatic drill bit unloading

**Acknowledgements**

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