DEVELOPMENT OF "TACTILE" WHEEL FOR ROVER MOBILITY, SURVEY AND SCIENCE

R. Toda, R. Ma, V. Scott, A. Fraeman, S. Moreland, M. Heverly, D. Hunter and B. Kennedy, Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Dr. Pasadena, CA 91109, risaku.toda@jpl.nasa.gov

Overview: Planetary rovers lack a basic capability that humans take for granted when traversing difficult terrain: the ability to “feel” the surface with which they are interacting. We developed a "tactile" wheel that demonstrates sensor integration enabling spatially resolved ground pressure and regolith moisture content sensing capabilities. These measurements will provide a continuous record of terrain properties over the vehicle path and will enable more proficient autonomous maneuvering traverses over difficult terrains.

Background: In the past, Nagatani and Shirai reported a rover wheel with four to eight embedded resistive pressure-sensors [1, 2]. Despitethe relatively small number of sensors, these wheels were able to characterize force distribution and sinkage in a controlled laboratory environment. A denser array of sensors would allow for continuous monitoring of surface condition while traversing long distances on planetary terrain. The real-time terrain information provided by such sensors would include rock angularity/roundedness and pressure-sinkage relationships, which would be useful for both scientific (terrain physical properties and terrain evolution) and engineering purposes (autonomous rover control such as hazard detection and obstacle avoidance).

Additional sensing capabilities that take advantage of a wheel’s continuous contact with a planetary surface can also be incorporated. Buehler proposed in-wheel impedance spectrometer, magnetometer, conductivity sensor, and electrometer for Lunar/Martian soil composition sensing [3]. Here we focus on regolith moisture sensing with spatial and temporal (e.g. diurnal and seasonal cycles) resolution to provide insight into modern-day volatile cycling and possibly locate resources for future in situ utilization.

Approach: Proof-of-principle prototypes of the tactile wheels using 1) inductive pressure sensor array, 2) fiber Bragg grating (FBG) strain sensor array, and 3) electrochemical impedance spectrometer (EIS) for soil moisture measurement have been studied. An inductive type pressure sensor array was chosen because it is promising for compatibility with Martian surface environment with further development. We also tested FBG sensor because it is readily compatible with new and emerging type of compliant mesh wheels currently being developed at NASA Glenn [4], and it greatly reduces wiring complexity.

Inductive pressure sensor: Figure 1(a) shows a prototype wheel with an inductive pressure sensor sheet and EIS electrode strips on-wheel. The customized inductive pressure sensor sheet with 1920 sensor nodes with 16 mm grid pitch [5] was mounted over the surface of a 20-inch diameter rigid plastic wheel. Two 1-inch wide nitinol electrodes spaced 1-inch apart were also attached on the outside periphery of the wheel and wired to the spectrometer [6]. Stainless steel grousers were placed over the pressure sensor sheet and the EIS electrodes. The steel grousers were electrically insulated from the EIS electrodes. A MEMS 3-axis accelerometer IMU was also mounted inside of the wheel for rotation angle sensing. These sensors were interfaced to a single-board computer and powered by a battery pack. The prototype wheel was attached to MSL-like "Scarecrow" test vehicle and tested at JPL Mars Yard facility. Figure 1(b) shows the schematic of this tactile wheel prototype. Figure 2 shows the obtained data snapshot. The image shows the wheel deeply buried in soft sand and the rover attempting to back out. The pressure map and histogram shown in Fig. 2 clearly indicate the depth of wheel sinkage and associated pressures. This relationship is governed by terrain physical properties, such as cohesion and angle of in-

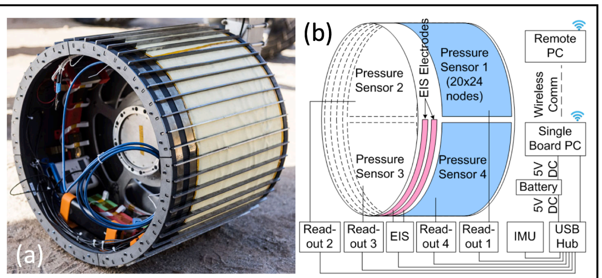

Fig. 1. (a) Tactile wheel prototype with inductive pressure distribution sensor and EIS electrodes. (b) Schematic of tactile wheel.

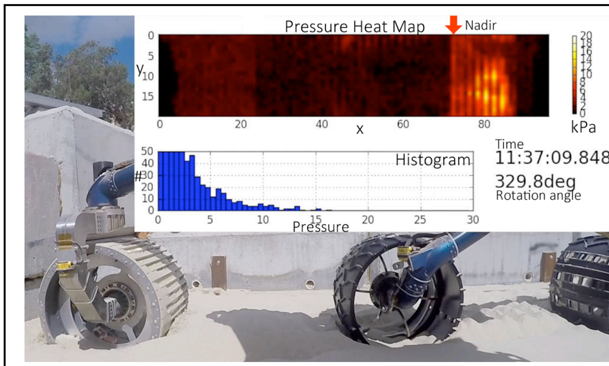

Fig. 2. Tactile wheel prototype tested at JPL’s Mars Yard test facility. Heat map shows pressure distribution. Red arrow indicate nadir direction

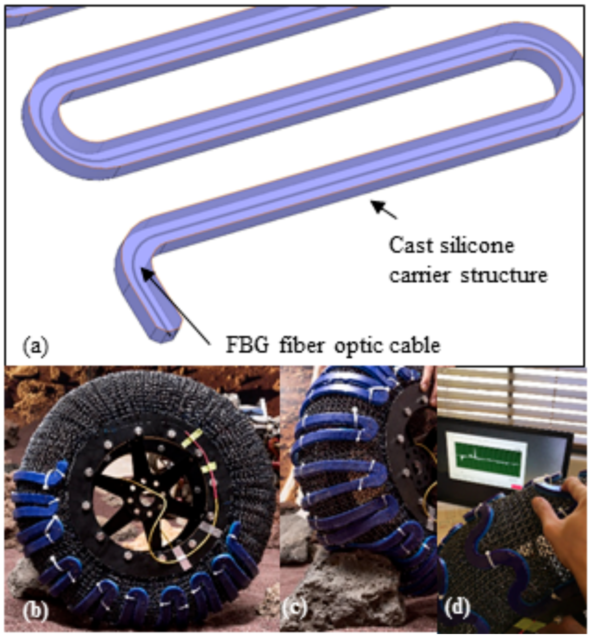

Fig 3. (a) Close-up view of FBG cable embedded in a cast silicone carrier structure, (b) Sensor is flexible and can (c) comform to the interior of deformable mesh wheel, (d) FBG raw output for localized contact event.

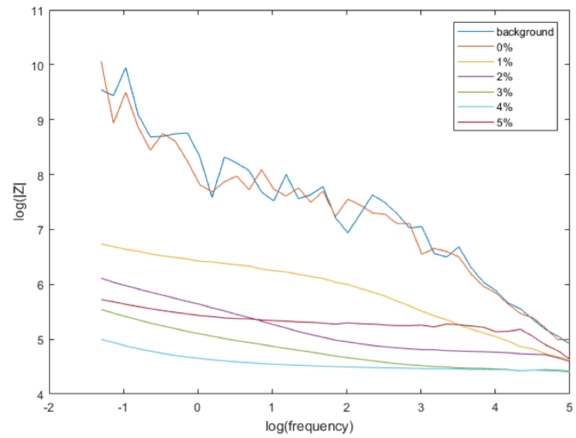

Fig.4. EIS data indicate drastically different impedance levesl for different levels of soil moisture (0 - 5 wt%) in soil samples

ternal friction. Knowledge of these parameters provides insight into landscape evolution [7] and can be incorporated into kinematic models that predict future driver performances [8,9]. In other tests, the pressure sensor was able to monitor driving on hard, angular basaltic rocks even though the steel grousers tends to attenuate pressure point loads.

FBG pressure sensor: Figures 3 shows a proof-of-concept FBG sensor mounted on a compliant rover wheel made with Nitinol wire mesh [4]. The FBG was embedded in cast silicone pattern and mechanically fastened to the surface of wheel. FBG sensors measure strain along its length at periodic intervals where a variations, or gratings, reside in the fiber. By attaching it offset from the wheel mesh's effective neutral plane, the measured strain reflects the bending deformation of the mesh wheel surface. In contrast to conventional sensing arrays, FBG sensors only require a single transmitter and receiver, though the complexity of the necessary data acquisition system is not yet compact enough for mobile applications [10].

EIS Soil Moisture Sensing: Figure 4 shows a plot of EIS data taken with sand from JPL's Mars Yard with different levels of moisture. Nitinol electrodes were chosen for mechanical properties, electrochemical stability, and ease for incorporation. This data was taken using smaller, representative electrodes in controlled laboratory environment and it shows distinct variance in impedance between dry versus wet sand over a wide frequency spectum. Field measurements were also carried out using electrodes mounted on the wheel, as shown in Figure 1, using the same material, width, spacing, and approximate contact area. Electrodes were designed to cover 270° of the wheel circumference to enable periodic background spectrum measurements with the electrodes not in contact with the ground. These field tests showed similar results, with clear differences between dry versus wet sand. Field tests were also done with a shortened, targeted spectral width to decrease collection time, enabling the wheel to be in motion while making the measurement.

Summary: Proof-of-concept "tactile" wheel prototypes with three sensor types have been built. The inductive and FBG pressure distribution sensors and soil moisture sensing using EIS have shown promising results and illustrate the significant benefit of in-wheel sensor integration for planetary rover ground operation engineering and science.

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