DESIGN OF A LUNAR DUST RESISTANT CONNECTION INTERFACE USING BIOMIMETIC STRATEGIES

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Abstract

In lunar exploration, dust poses a significant problem due to its pervasiveness, adherence, and abrasiveness, causing premature failure of mechanisms. Successful operation of autonomous equipment in the harsh lunar environment requires innovative methods of dust protection, especially for exposed connection interfaces. In eventual robotic lunar exploration missions, lunar dust control will be a major factor affecting mission lifetimes and operations. Biomimetic inspired concepts are developed to design an interface allowing electrical connection between a lunar rover and interchangeable instruments. A proof-of-concept prototype of the interface has been constructed to demonstrate system functionality under laboratory conditions.

Dans le cadre de l'exploration lunaire, la poussière représente une difficulté importante à cause de son omniprésence, de son adhérence et de sa capacité d'abrasion, tout ceci menant à des bris prématurés des mécanismes. Des méthodes innovantes en protection contre la poussière sont requises pour réussir à faire fonctionner de l'équipement de façon autonome, particulièrement en ce qui concerne les interfaces de connexion exposées à l'environnement. Lors d'éventuelles missions lunaires robotiques, le contrôle de la poussière lunaire sera un facteur déterminant pour la durée de la mission et pour le type d'opérations possibles. Des concepts inspirés de la biomimétique sont développés pour concevoir une interface permettant une connexion électrique entre une plateforme mobile lunaire et des instruments interchangeables. Un prototype de l'interface est construit pour démontrer la fonctionnalité du système dans des conditions de laboratoire.

Introduction

At the onset of the Apollo missions, little was known about lunar dust. Mechanisms were built according to standards used for dusty environments on earth. However, lunar dust is comprised of highly abrasive, electrically-charged particles with sizes ranging from one hundredth of a micron to one hundred microns. The electrostatic properties come from the small amount of iron present in the dust, allowing it also to react to magnetic fields.

During the Apollo missions, dust posed a significant problem due to its pervasiveness, adherence, and abrasiveness, causing premature failure of structures and mechanisms. Solar winds charge the dust particles, and as a result, these particles float above the surface for extended periods of time. Any motion at the surface displaces the dust, and the combined effect of low gravity and electrostatic properties sends the dust in the air at a certain speed.

Future lunar missions will involve rovers that can stay on the moon for extended periods of time to collect the maximum amount of scientific data, and potentially, the capacity to switch payloads. Switching payloads on a rover will require a connecting interface. The pervasive lunar dust could hamper this capacity. As dust clings to all surfaces, any connecting interface needs to be cleaned of its dust prior to connection, or to be sealed until the connection occurs. The goal of this project was to design a connecting interface for the lunar environment. Biomimetic methods were used to generate ideas.

Biomimetic Design

In biomimetic design, biological phenomena serve as stimuli for solving engineering problems. An often-cited example of biomimetic design is how Velcro emulates hook structures found on burrs observed to attach to fur and clothing. While Velcro resulted from the designer's own experience with burrs, many designers may not know of all relevant biological phenomena that could solve a given problem. Also, the creation of a database to catalog all of biological phenomena for engineering design is a formidable task that is also subject to the compilers' personal bias. Therefore, Vakili and Shu [1] developed a method to search existing biological knowledge in natural-language format to identify relevant biological analogies. The initial corpus, or text, is an undergraduate level biology textbook, Life, the Science of Biology [2]. Search keywords correspond to verbs that describe the desired function of the solution, and identify biological phenomena that can be used either directly for a design solution or as a starting point for further research into useful biological phenomena.

Since we are seeking design solutions that *protect* equipment from lunar regolith, an obvious starting keyword that describes the intended function of our solution is *protect.* Because we are searching for instances of keywords in natural-language, as opposed to a database using specified keywords, a first step is to find synonyms, or other words related to initial keywords. For example, *defend* is a keyword related to *protect*. Chiu and Shu [3] found that because of lexical differences between biology and engineering domains, searching biological knowledge in natural-language format for instances of engineering keywords may not yield good results. Therefore a method was developed that identifies biologically meaningful keywords. This method uses a combination of word collocation (which words occur together in an excerpt) and frequency analysis (how frequently words occur in an excerpt). Chiu and Shu [3] confirmed that the keyword *defend* is related to *remove,* in that biological entities *remove/clean* themselves as a defensive mechanism. Furthermore, troponyms (or more specific manners) of *remove* include "pull", "harvest", "eliminate", "excrete", "shed", "draw", "pump" and "kill".

Searching for instances of "excrete" revealed how most animals have tubular guts that excrete wastes. Furthermore, peristalsis is a wave of smooth muscle contraction that moves food through the gut. How peristalsis moves food through the gut is used as an analogy for how to move lunar regolith.

Design

As stated in the previous section, the prototype design was based on peristalsis. The concept focuses on a tubular connection interface surrounded by magnetic coils as shown in Figure 1. These coils are driven by synchronized currents in order to induce varying magnetic gradients through the tunnel. The lunar regolith particles, being ferromagnetic, will react to the magnetic gradients, and a force proportional to the square of the field gradient will be exerted on them, thus expelling them from the connection tube. The connecting area can therefore be cleaned of its dust prior to connection. Because there are no moving mechanical parts to protect the connecting area, the risks of degradation due to dust or failure are minimized.

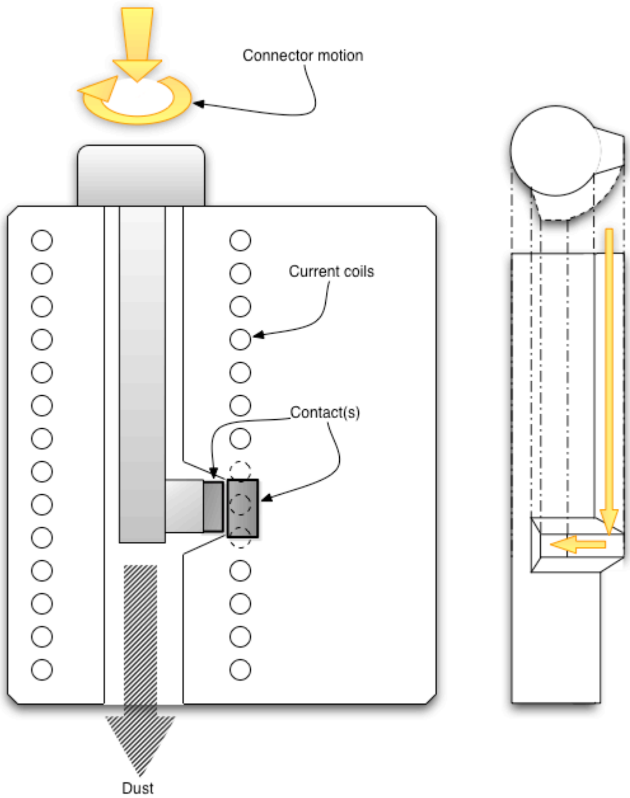

Figure 1: Conceptual Connector Design

In order to obtain a satisfactory gradient distribution ensuring a directional particle flow along the axis of the connector, it was determined that the coils surrounding the tube had to be wound in such a way that each coil overlaps half of the preceding and following coil (see Figure 2). This design optimizes gradient distribution in the tube, as the gradient of the field generated by a current coil is maximal at its extremities and nearly nil at the center. By winding the coils in this fashion, we can guarantee that every region of the tube where field gradient is low when one set of coils is enabled will present a maximal gradient when other coils are activated. This will have the effect of eliminating any stale regions in the tube where the dust would never be exposed to high gradients. By activating the coils sequentially, we can effectively carry the dust along the tube by creating zones of high gradient one in front of another along the length of the tube.

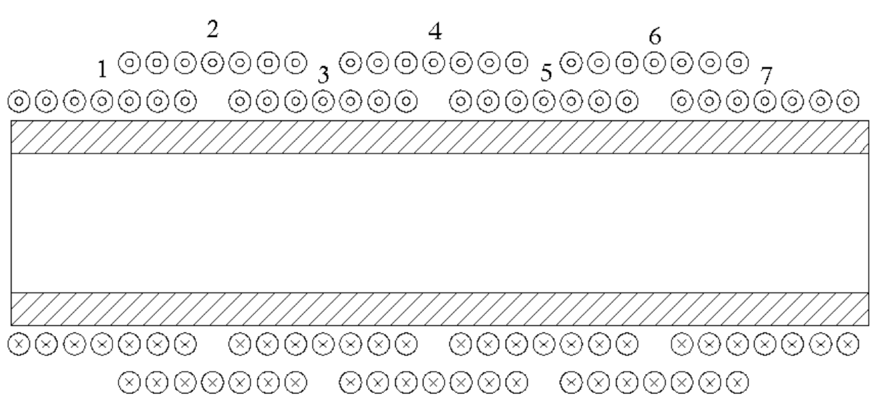

Figure 2: Sectional View of the Tube and Coils

The prototype was designed as a horizontal tube, with seven overlapping wire coils around it as shown in Figure 2. The tube was made of aluminum, a non-ferromagnetic metal, in order to maximize magnetic field penetration inside the tube. The coils were hand-wound at about 600 turns each using standard 29 AWG coated copper winding wire. The tube itself has an external diameter of 19 mm and a length of 10.16 cm, each of the coils spanning about 2.54 cm along the tube.

The coils were activated sequentially from number 1 to 7 to induce a dust flow. In order to activate these coils, the circuit presented in Figure 3 was designed.

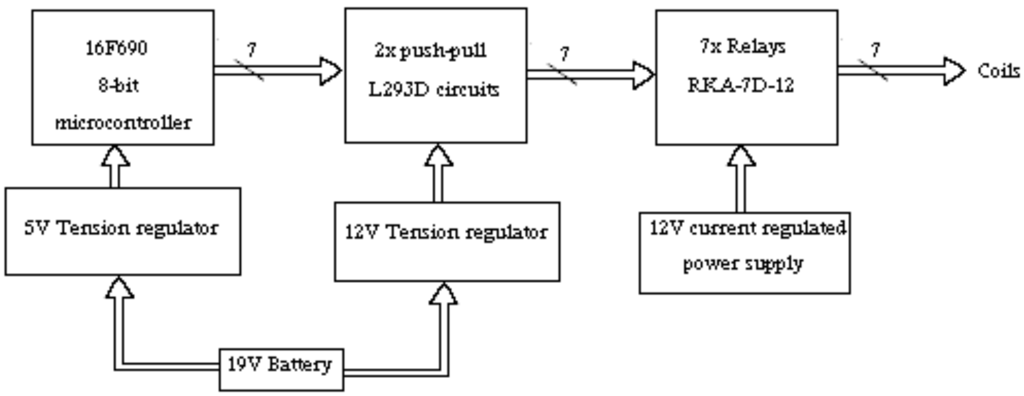

Figure 3: Circuit Block Diagram

The current was supplied to the coils by a standard 12 V DC power supply with a current limiter. To achieve the coil lighting sequence, RKA-7D-12 relays were used. They also provided electrical isolation between the coils and the electronic control circuit, which can be easily damaged by inductive charges such as coils powering on and off. The enabling sequence signal was provided by a general purpose PIC16F690 8-bit CMOS microcontroller. It was used in output mode and provided 7 different digital signals. The relays need 12 V and 261 mW to switch into 'on' position. Being unable to supply such current and voltage, two standard L293D push-pull four-channel drivers with diodes were used. They provided the voltage and current required by the relays and also they isolated the microcontroller from the switching coils activating the relay switches. Power was supplied to the electronic control circuit with two standard 9V batteries providing 18 V. This voltage was lowered to 5V for the microcontroller and 12V for the push-pull chips using standard LM7805 and LM7812 tension regulators.

Experimental Results

The experiment was set up as shown in Figure 4. The prototype was elevated and supported by a wooden stand. A small amount of the regolith dust simulant CHENOBI, containing approximately 2% of iron, was placed in the middle of the aluminum tube. Two receptacles were placed under each opening of the tube to collect the dust exiting. A transparent box was placed over the tube in order to prevent the air currents from affecting the results.

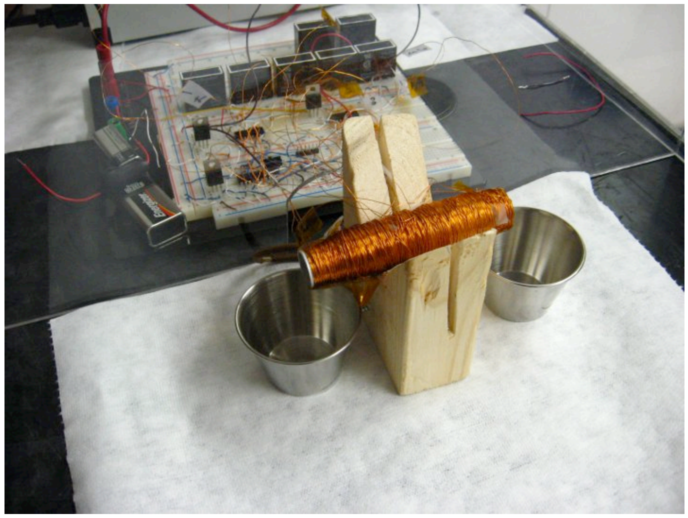

Figure 4: Experimental setup

The experiment was conducted in a time period of about 10 minutes. During that time, each coil was sequentially activated for a period of 1 second and then deactivated. The sequence goes from Coil 1 to Coil 7 (see Figure 2) and is repeated until the end of the experiment, thus resulting in a magnetic peristalsis effect on the dust.

Once the experiment was completed, we examined the inside of the receptacles and observed that the one near Coil 7 was containing dust. The amount of collected dust was small and the trace it left on a white cloth can be seen in the red circle on Figure 5.

Fig 5 : Collected dust out of coil 7 on white rag

Conclusion

The pervasiveness of lunar dust, as well as its abrasiveness, will complicate any connection tasks on the moon. These connection tasks could be necessary for robotic operations where payloads on the rover could be interchanged. By using a biological phenomenon as inspiration, a design was developed to allow cleaning of the interface before connection. The prototype demonstrated the functionality of the design that thus, allows use of connectors on the moon. The next steps involve constructing a more representative prototype with full connecting ability.

References

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