Title of Investigation:

Virtual Feel Robotic Assembly

Principal Investigator:

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Other In-House Members of Team:

Mathew Chen (Student Intern), India Jacobs (Student Intern), Travis Coleman (Student Intern), Rajesh V. Karyampudi (Student Intern)

Other External Collaborators:

Roopnarine and Saase Singe (Honeybee Robotics)

Initiation Year:

FY 2003

Aggregate Amount of Funding Authorized in FY 2004 and Earlier Years:

$13,000.00 in FY 2003; the Robotics Intern Team performed research in FY 2005 so no DDF funds were needed. Research consisted of computer modeling and circuit work, all performed by interns.

Funding Authorized for FY 2005:

$12,000

Actual or Expected Expenditure of FY 2005 Funding:

In-House: $12,000 was spent in-house on computer modeling efforts.

Status of Investigation at End of FY 2005:

To be continued, pending further developments

Expected Completion Date:

TBD

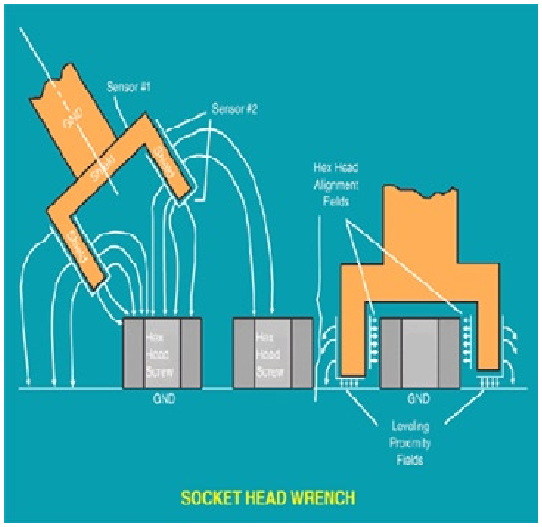

Figure 1. "Virtual Feel" Field Lines

Purpose of Investigation:

Precision assembly using robotics currently lacks a proper sense of touch. For space applications— where time delays can create challenges— this means that the robot can miss fasteners or jam. Machine vision can compensate for this deficiency, but camera views of wrench/fastener contact surfaces sometimes are obscured and force/torque sensing is effective only after contact. The purpose of this investigation was to establish the theoretical basis and argument for multi-degree of freedom or "Virtual Feel," which provides non-contact, precision guidance and final alignment before final touch down and the application of force/torque through the use of electric field lines that are like invisible whiskers.

"Virtual Feel" performs the same function as "real feel" and does so just before contact. The electric field lines collect near the nearest point of contact, take the place of fingertip skin sensors to warn the operator of impending contact and stop motion before contact. This gives the operator time to react and catch up and compensate for time delay-coordination. In "Virtual Feel," the sensing tools may be tough and unyielding, but the electric fields are flexible, compliant, and sensitive like invisible whiskers. Equally important, the concept works in space, is simple, and is very practical.

"Virtual Feel" must work for all materials and based on capacitive sensing. It must discriminate between electrical conductors and electrical insulators. Capaciflectors (essentially a "Driven Source") senses electrical conductors better than electric insulators. "Driven Grounds" enable electrical insulators to be sensed apart from electrical conductors. Switching back and forth rapidly between the two states ("Blinking") enables "Virtual Feel" tools to determine object material (insulator or conductor) and, thereby, to operate in the vast majority of space robotic situations.

Accomplishments to Date:

1. An early version of "Virtual Feel" was demonstrated to NASA Headquarters in 2005. The demonstration helped secure initial funding to study robotic servicing of Hubble.

2. "Virtual Feel," "Driven Ground" and "Blinking Configuration" were developed to the point of being detailed concepts, ready and worthy of further development. "Driven

Ground" enables electric flux to be measured through an electrical insulator. "Driven Source" (capaciflector) enables electric flux to be measured to an electrical conductor. Blinking Configuration allows the "Virtual Feel" sensor to switch between the two and to determine what materials are involved. This, in turn, allows the sensor to operate in the vast majority of operational circumstances. Previously, the insulator part of the puzzle was missing.

3. Because of the accomplishments listed above, the project attracted a NASA robotics intern team to further develop the "Virtual Feel" concept.

4. The robotics group at the Naval Research Lab recently has initiated a "Virtual Feel" project as part of its "SUMO" project for precision robotic assembly and servicing in space. This is a joint Navy/DARPA project that will ultimately benefit NASA in on-orbit robotic servicing.

5. Microwave Water Detector Lunar Water Sensor is being proposed by the Goddard Space Flight Center to measure the presence and extent of ice water crystals in lunar soil. A 7-person, multi-disciplinary team is preparing a proposal. The component technologies of "Virtual Feel," (capaciflector, driven ground, capaciflector camera, et al) constitute the heart of the proposed sensor.

Patents:

Invention disclosure—"Virtual Feel"—was submitted in 2005. The Goddard Patent Office processed the application and filed it with the U.S. Office of Patents and Trade Marks, where it is currently being processed to full patent.

Invention disclosure—"Driven Ground"—was submitted in 2005. The Goddard Patent Office has decided to process "Driven Ground" to full patent, has allocated the funds to do so and is proceeding.

Planned Future Work:

We plan to perform a simulation mission, using high-fidelity models of actual tools, work pieces, and surrounding circumstances. Of particular interest is the situation in which dielectric films and structures are present, along with conductors. Once this is accomplished, other mission scenarios will be examined, leading to a methodology in which a smart tool and end-effector set can be optimally and efficiently designed to successfully execute any mission. This will be followed by:

- Construct and demonstrate actual hardware.
- Initiate computer extrasensory visualization techniques to aid in the design of other sensing systems, based on physics other than electric field capacitance.
- Use extrasensory computer visualization to make robot control and tool sensor information more efficient and effective.
- Support the MWD Lunar Water Sensor work and improve the sensor circuitry in the process.

Key Points Summary:

Project's innovative features: The Concept of "Virtual Feel" is new. The Concept of a "Driven Ground" is new. The Concept of a "Blinking Driven Ground/Driven Source" to achieve optimum "Virtual Feel" is new. The Concept of using computer electric field visualization to replace experimental work in the laboratory and to provide better results in the process is new.

Potential payoff to Goddard/NASA: The technology is central to safe and efficient robotic precision assembly/disassembly. It also enables the MWD Lunar Sensor to measure ice water crystals in lunar soil. This effort is central to Goddard's part of the Lunar Exploration Initiative.

The Criteria for success: The "Driven Ground" concept was proven in hardware and was proven in computer modeling. The "Virtual Feel" invisible whiskers were successfully modeled and validated. "Virtual Feel" sensing for multiple degrees-of-freedom was successfully validated to a first approximation and the theoretical basis for the concept was established. Capaciflector ("Driven Source") and "Virtual Feel" precision assembly with multiple sensors have been proven many times over.

Technical risk factors: Computer modeling and hardware development take time and funding to solve the many detail issues, but there are no fundamental hurdles.