The Alpha-Proton-X-ray Spectrometer Deployment Mechanism -- An Anthropomorphic Approach to Sensor Placement on Martian Rocks and Soil

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The Mars Pathfinder mission promises to reap a harvest of geological information about Mars. One of the nearly half dozen instruments making this science data possible is the alpha proton x-ray spectrometer (APXS). Using a curium source and backscattering techniques, the APXS will determine the elemental composition of rocks and the soil around the landing site. To ensure information of high fidelity, the APXS sensor face must be aligned within 20° to the surface of each rock and soil sampling location and be held there for up to 10 hours. The most straightforward way to accomplish this task is to have a stowaway take the sensor in hand and place it on the rock or soil. The next best answer is the anthropomorphic deployment mechanism (ADM).

Consisting mainly of a flexible wrist capable of +/-25 degrees bending compliance in two axes, a parallel link arm, and a 2000 to 1 brush dc motor actuator, the ADM mounts on the back of the Mars Rover. Working with the rover, the ADM both actively and passively positions the APXS sensor head against a chosen target. If the actuator ever breaks, a fail-safe mechanism composed of a Negator spring pack and a low-temperature-melting metal coupler decouples the mechanism from the actuator and retracts it into its stowed position,

Many technical challenges drove the ADM design evolution. The foremost obstacle was providing adequate sensor head compliance within the allowed volume. Five degrees of freedom are necessary to align a cylinder to a jagged rock The front face of the cylinder must be able to stay stationary while the rest of the cylinder rotates into place. Furthermore, the support of the cylinder must be far from the front edge to allow the cylinder to butt up against the rock without jamming or hitting the support structure. Most design ideas were either unstable, took up too much room, weighed too much, or didn't allow for adequate translation. However, the flexible wrist, consisting of a base and three support rods forming an open tetrahedron, with a helical-cut spring at each support-base interface and a hip joint at each rod/cylinder interface, keeps the support structure at the back of the cylinder while theoretically allowing for +/-90° of compliance before going overcenter. Picking the geometry correctly limits the front surface translation while the rest of the cylinder pivots about a temporary center of rotation in front of the cylinder. Because the center of rotation is in front of the cylinder, the tilting motion is always stable.

The next obstacle to overcome was deploying the sensor to a rock or down to the soil. The mechanism must keep the sensor head in close to the back of the rover to minimize rover turn radius but extend out to a rock so that the top solar panel of the rover will not bump into the rock when it backs the sensor in. Another constraint on the mechanism is that the final motion down to the soil surface must be vertical to eliminate the possibility of wedging in the sensor head. In effect then, the mechanism must extend the sensor back, rotate the sensor down to the ground, and then once again extend it straight down to the soil.

Parallel links and a spring-loaded stop accomplish this maneuver. In its stowed position, the parallel links keep the flexible wrist pulled back. When the mechanism actuates, the parallel links translate the head out 2 inches. Then, the back link contacts a spring-loaded stop, Because the links cannot extend anymore, the entire parallel link configuration rotates to the surface until the bottom traversing link hits a stop mounted on the mechanism shelf. The links stop rotating, and the back link starts overpowering the spring-loaded stop, Once again the parallel links extend the sensor head, this time to the soil,

Another difficult design problem was knowing when the sensor head is adequately aligned to its target. A bumper mounted on the front of the cylinder with greater than 20 degrees of compliance is required to indicate when adequate aligned is attained. However, with a 2 inch diameter cylinder, the bumper must stick out 1 inch past the cylinder. A bumper out that far not only increases the rover turn radius, but it also increases the probability that the bumper will catch on rocks or scoop up dirt. Therefore, a best-effort approach is more acceptable. Three stubby spring-loaded plungers connect the bumper to the cylinder. LED/phototransistor pairs mounted around the plungers give indication when the bumper contacts a target surface. Another sensor loaded by a stiff spring is mounted on the base of the flexible wrist. When contact is made with a target surface at least one sensor gives an indication. After the flexible wrist has reached its end of travel, the compliant force from the actuator or the rover builds up until the sensor on the wrist base gives an indication. In the case when the sensor aligns completely before the wrist reaches end of travel, the three sensors will give an indication and the actuator or rover will stop.

Tying the mechanism down during launch, descent and landing was the last great technical obstacle. The optimal approach is to hold the sensor down to the rover and eliminate any direct tie to the lander. However, such a stowage device is too heavy for the rover to carry. Taking advantage of the compliance of the mechanism, the sensor is instead pulled down to the lander mounting surface and held in place in a launch support saddle with a cable. The helical springs in the wrist attenuate rover/lander load transfer through the mechanism.

The ADM is an amalgamation of unique solutions to challenging design problems, The resulting design is light, flexible, and nearly autonomous. Its straightforward operation rivals that of a human arm in simplicity and elegance. Its successful operation will greatly contribute to the cornucopia of useful information gleaned from the Mars Pathfinder mission.