Electronics/Computers

Using Transponders on the Moon to Increase Accuracy of GPS

Ranging to the Moon would be unaffected by the terrestrial atmosphere.

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It has been proposed to place laser or radio transponders at suitably chosen locations on the Moon to increase the accuracy achievable using the Global Positioning System (GPS) or other satellite-based positioning system. The accuracy of GPS position measurements depends on the accuracy of determination of the ephemerides of the GPS satellites. These ephemerides are determined by means of ranging to and from Earth-based stations and consistency checks among the satellites. Unfortunately, ranging to and from Earth is subject to errors caused by atmospheric effects, notably including unpredictable variations in refraction.

The proposal is based on exploitation of the fact that ranging between a GPS satellite and another object outside the atmosphere is not subject to error-inducing atmospheric effects. The Moon is such an object and is a convenient place for a ranging station. The ephemeris of the Moon is well known and, unlike a GPS satellite, the Moon is massive enough that its orbit is not measurably affected by the solar wind and solar radiation.

According to the proposal, each GPS satellite would repeatedly send a short laser or radio pulse toward the Moon and the transponder(s) would respond by sending back a pulse and delay information. The GPS satellite could then compute its distance from the known position(s) of the transponder(s) on the Moon.

Because the same hemisphere of the Moon faces the Earth continuously, any transponders placed there would remain continuously or nearly continuously accessible to GPS satellites, and so only a relatively small number of transponders would be needed to provide continuous coverage. Assuming that the transponders would depend on solar power, it would be desirable to use at least two transponders, placed at diametrically opposite points on the edges of the Moon disk as seen from Earth, so that all or most of the time, at least one of them would be in sunlight.

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Controller for Driving a Piezoelectric Actuator at Resonance

Unpredictable variations in resonance frequency are tracked.

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A digital control system based partly on an extremum-seeking control algorithm tracks the changing resonance frequency of a piezoelectric actuator or an electrically similar electromechanical device that is driven by a sinusoidal excitation signal and is required to be maintained at or near resonance in the presence of uncertain, changing external loads and disturbances. Somewhat more specifically, on the basis of measurements of the performance of the actuator, this system repeatedly estimates the resonance frequency and alters the excitation frequency as needed to keep it at or near the resonance frequency. In the original application for which this controller was developed, the piezoelectric actuator is part of an ultrasonic/sonic drill/corer. Going beyond this application, the underlying principles of design and operation are generally applicable to tracking changing resonance frequencies of heavily perturbed harmonic oscillators.

Resonance-frequency-tracking analog electronic circuits are commercially available, but are not adequate for the present purpose for several reasons:

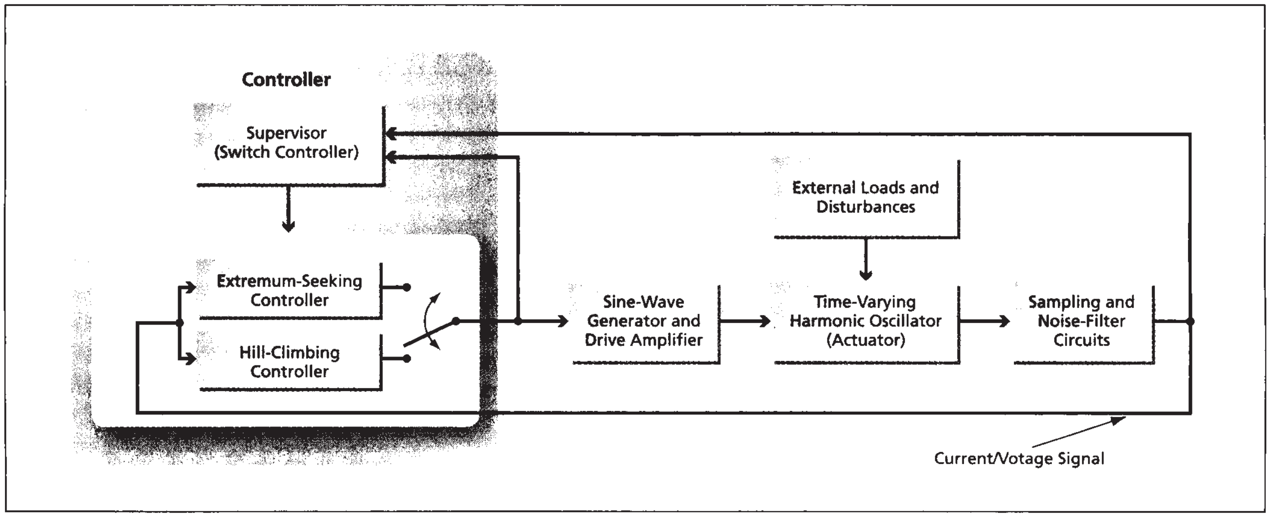
- The input/output characteristics of analog circuits tend to drift, often necessitating recalibration, especially whenever the same controller is used in driving a different resonator.
- In the case of an actuator in a system that has multiple modes characterized by different resonance frequencies, an analog controller can tune erroneously to one of the higher-frequency modes.
- The lack of programmability of analog controllers is problematic when faults occur, and is especially problematic for preventing tuning to a higher-frequency mode.

In contrast, a digital controller can be programmed to restrict itself to a specified frequency range and to maintain stability even when the affected resonator is driven at high power and subjected to uncertain disturbances and variable loads.

The present digital control system (see figure) is implemented by means of an algorithm that comprises three main subalgorithms: a hill-climbing control algorithm, an estimation-based extremum-seeking control (ESC) algorithm, and a supervisory algorithm. The hill-climbing algorithm is useful for coarse tracking to find and remain within the vicinity of the resonance. The ESC algorithm is not capable of coarse resonance tracking, but is capable of fine resonance tracking once the estimates of parameters generated by the hill-climbing algorithm have converged sufficiently. On the basis of the parameter-estimation errors, the supervisory algorithm switches operation to whichever of the other two algorithms performs best at a given time.

For the purpose of the control algorithm, the performance of the actuator is quantified in terms of the ratio between the time-averaged drive-voltage amplitude and the time-averaged drive current amplitude during a sampling time period. In the hill-climbing algorithm, the excitation frequency during the next sampling period is incremented or decremented by an arbitrary fixed step. If the increment or decrement results in an increase in the current/voltage ratio, then the direction of change (increase or decrease, respectively) of frequency is accepted and another such change (increment or decrement, respectively) is made during the following sampling period. If, on the other hand, the increment or decrement results in a decrease in the current/voltage ratio, then the direction of change of frequency during the following sampling period is reversed. The process as described thus far is repeated, causing the current/voltage performance to climb to one of the resonance peaks and eventually to oscillate about the peak. In order to prevent climbing of one of the undesired higher-frequency resonance peaks, it is necessary to choose the starting excitation frequency near the desired peak and to impose a limit on the excursion from the starting frequency.

Once the excitation frequency has begun to oscillate about the peak, the supervisory algorithm switches operation to the ESC algorithm, which uses past as well as present input/output data to make a least-squares estimate of the resonance frequency. The estimation task involves



This **Resonance-Tracking Controller** includes three main subsystems that function together to effect a combination of coarse and fine frequency tracking optimized to maintain operation at a desired resonance and avoid undesired resonances.

updating two scalar parameters of a quadratic model that represents the input/output map of the actuator resonance. After each sampling period, the new input/output data pair is added to the collection of past data pairs, such that information regarding the input/output relationship of the actuator increases over time; in other words, as the input/output information comes in, the algorithm tries to improve the fit between the quadratic model near resonance and all the past input/output data up to the current time. Once the estimated parameters have converged sufficiently, the excitation frequency is updated according to a simple formula that represents a maximizer associated with the quadratic model. In the event that the estimates begin to diverge beyond a specified limit, the supervisory algorithm switches operation back to the hill-climbing algorithm.

This work was done by Jack Aldrich, Yoseph Bar-Cohen, Stewart Sherrit, Mircea Badescu, Xiaoqi Bao, and Zensheu Chang of Caltech for NASA's Jet Propulsion Laboratory. For further information, contact iaoffice@jpl.nasa.gov. NPO-43519