Detecting Moving Targets by Use of Soliton Resonances

Faint targets moving uniformly would be distinguished from background clutter.

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A proposed method of detecting moving targets in scenes that include cluttered or noisy backgrounds is based on a soliton-resonance mathematical model. The model is derived from asymptotic solutions of the cubic Schroedinger equation for a one-dimensional system excited by a position-and-time-dependent externally applied potential. The cubic Schroedinger equation has general significance for time-dependent dispersive waves. It has been used to approximate several phenomena in classical as well as quantum physics, including modulated beams in nonlinear optics, and superfluids (in particular, Bose-Einstein condensates). In the proposed method, one would take advantage of resonant interactions between (1) a soliton excited by the position-and-time-dependent potential associated with a moving target and (2) "eigen-solitons," which represent dispersive waves and are solutions of the cubic Schroedinger equation for a time-independent potential.

In nondimensionalized form, the cubic Schroedinger equation is

$$iu_t + u_{xx} + \nu|u|^2u = Vu,$$

where x is the nondimensionalized position coordinate, t is nondimensionalized time, $u(x,t)$ is a complex state variable, ν is a coupling constant, $V(x,t)$ is the nondimensionalized externally applied potential, and the subscripts denote partial differentiation with respect to the variables shown therein. The equation admits of a variety of solutions that have different qualitative and quantitative properties: Depending on the magnitudes and signs of model parameters, the model can represent a positive or negative moving target potential that induces "bright" or "dark" solitons in an attractive or repulsive Bose-Einstein condensate.

In the proposed method, one would exploit a property of "bright" soliton solutions: Any uniformly moving component of an external potential (for example, representing uniform motion of a target) is amplified, while the remaining components (for example, representing noise) are dispersed. This phenomenon is similar to a classical resonance, in which out-of-resonance components eventually vanish.

A target-detection algorithm according to the proposed method would begin with conversion of readings of target-motion-detecting sensors into values of a fictitious moving potential. The values would, in turn, be fed as input to a computational model of a dynamic system governed by the cubic Schroedinger equation. The only surviving output signal components would be those having space and time dependence proportional to the moving potential. The algorithm could be implemented computationally — possibly by use of a neural-network mathematical model. Alternatively, the algorithm could be implemented by use of a physical model — for example, a superfluid or a nonlinear optical system.

The algorithm could be expanded to detect a moving target in a two- or three-dimensional space. It would not be necessary to develop a two- or three-dimensional soliton-resonance model. For this purpose, it would suffice to use two or three one-dimensional soliton-resonance models, each of which would be used to detect the projection of the motion of the target onto one of the two or three coordinate axes. One would then construct a representation of the two- or three-dimensional target motion from the outputs of the algorithm for the two or three axes.

This work was done by Michael Zak and Igor Kulikov of Caltech for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP (see page 1).*
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Finite-Element Methods for Real-Time Simulation of Surgery

Some accuracy is traded for computational speed.

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Two finite-element methods have been developed for mathematical modeling of the time-dependent behaviors of deformable objects and, more specifically, the mechanical responses of soft tissues and organs in contact with surgical tools. These methods may afford the computational efficiency needed to satisfy the requirement to obtain computational results in real time for simulating surgical procedures as described in "Simulation System for Training in Laparoscopic Surgery" (NPO-21192) on page 31 in this issue of *NASA Tech Briefs*.

Simulation of the behavior of soft tissue in real time is a challenging problem because of the complexity of soft-tissue mechanics. The responses of soft tissues are characterized by nonlinearities and by spatial inhomogeneities and rate and time dependences of material properties. Finite-element methods seem promising for integrating these characteristics of tissues into computational models of organs, but they demand much central-processing-unit (CPU) time and memory, and the demand increases with the number of nodes and degrees of freedom in a given finite-element model. Hence, as finite-element models become more realistic, it becomes more difficult to compute solutions in real time.

In both of the present methods, one uses approximate mathematical models — trading some accuracy for computational efficiency and thereby increasing the feasibility of attaining real-time up-

date rates. The first of these methods is based on modal analysis. In this method, one reduces the number of differential equations by selecting only the most significant vibration modes of an object (typically, a suitable number of the lowest-frequency modes) for computing deformations of the object in response to applied forces.

The second method involves the use of the spectral Lanczos decomposition to obtain explicit solutions of the finite-element equations that describe the dynamics of the deformations. The explicit solutions are used to generate an "impedance map" of the object: this involves the precomputation of displacement fields (in effect, a look-up table), each field being the response to a unit load along each nodal degree of freedom. Thereafter, the deformation of an object is computed as a superposition of the individual responses of the nodes. In computing the response of a given node, one uses the responses of only those neighboring nodes that lie within an arbitrary radius of influence. This method is suitable for a linear (but not for a nonlinear) finite-element model of tissue.

This work was done by Cagatay Basdogan of Caltech for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP (see page 1).*

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