

cules or building a habitat. From observations of other successful social online games such as Farmville and Restaurant City, a common element of these games is having eye-catching and cartoonish characters, and interesting animations for all activities. This will create a fun, educational, and rewarding environment.

The player needs to accumulate points in order to be awarded special

items needed for advancing to higher levels. Trophies will be awarded to the player when certain goals are reached or tasks are completed. In order to acquire some special items needed for advancement in the game, the player will need to visit his/her neighboring towns to discover the items. This is the social aspect of the game that requires the player to go out of his/her own establishment to

explore what is in the neighborhood. Spaceville will take advantage of Facebook's successful architecture to inspire a new audience of scientists and engineers for the future.

*This work was done by Ben Lui and Barbara Milner of Goddard Space Flight Center, Dan Binebrink of SGT Inc., and Heng Kuok of Sigma Space Corp. Further information is contained in a TSP (see page 1). GSC-16214-1*

---

## Σ Rotorcraft Diagnostics

*John H. Glenn Research Center, Cleveland, Ohio*

Health management (HM) in any engineering systems requires adequate understanding about the system's functioning; a sufficient amount of monitored data; the capability to extract, analyze, and collate information; and the capability to combine understanding and information for HM-related estimation and decision-making. Rotorcraft systems are, in general, highly complex. Obtaining adequate understanding about functioning of such systems is quite difficult, because of the proprietary (restricted access) nature of their designs and dynamic models. Development of an EIM (exact inverse map) solution for rotorcraft requires a process that can overcome the above-mentioned difficulties and maximally utilize monitored information for HM facilitation via employing advanced analytic techniques.

The goal was to develop a versatile HM solution for rotorcraft for facilitation of the Condition Based Maintenance Plus (CBM+) capabilities. The effort was geared towards developing analytic and reasoning techniques, and proving the ability to embed the required capabilities on a rotorcraft platform, paving the way for implementing the solution on an aircraft-level system for consolidation and reporting.

The solution for rotorcraft can be used offboard or embedded directly onto a rotorcraft system. The envisioned solution utilizes available monitored and archived data for real-time fault detection and identification, failure precursor identification, and offline fault detection and diagnostics, health condition forecasting, optimal guided troubleshooting, and maintenance decision support. A variant of the onboard ver-

sion is a self-contained hardware and software (HW+SW) package that can be embedded on rotorcraft systems.

The HM solution comprises components that gather/ingest data and information, perform information/feature extraction, analyze information in conjunction with the dependency/diagnostic model of the target system, facilitate optimal guided troubleshooting, and offer decision support for optimal maintenance.

*This work was done by Deepak Haste, Mohammad Azam, Sudipto Ghoshal, and James Monte of Qualtech Systems for Glenn Research Center. Further information is contained in a TSP (see page 1).*

*Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Innovative Partnerships Office, Attn: Steven Fedor, Mail Stop 4-8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-18672-1.*

---

## Σ Recursive Branching Simulated Annealing Algorithm

**The algorithm can be applied to a wide variety of optimization problems.**

*Goddard Space Flight Center, Greenbelt, Maryland*

This innovation is a variation of a simulated-annealing optimization algorithm that uses a recursive-branching structure to parallelize the search of a parameter space for the globally optimal solution to an objective. The algorithm has been demonstrated to be more effective at searching a parameter space than traditional simulated-annealing methods for a particular problem of interest, and it can readily be applied to a wide variety of optimization problems, including those with a parameter space having both discrete-value parameters (combinatorial) and continuous-variable parameters. It can

take the place of a conventional simulated-annealing, Monte-Carlo, or random-walk algorithm.

In a conventional simulated-annealing (SA) algorithm, a starting configuration is randomly selected within the parameter space. The algorithm randomly selects another configuration from the parameter space and evaluates the objective function for that configuration. If the objective function value is better than the previous value, the new configuration is adopted as the new point of interest in the parameter space. If the objective function value is worse than the previous value, the new configura-

tion may be adopted, with a probability determined by a temperature parameter, used in analogy to annealing in metals. As the optimization continues, the region of the parameter space from which new configurations can be selected shrinks, and in conjunction with lowering the annealing temperature (and thus lowering the probability for adopting configurations in parameter space with worse objective functions), the algorithm can converge on the globally optimal configuration.

The Recursive Branching Simulated Annealing (RBSA) algorithm shares some features with the SA algorithm, notably in-

cluding the basic principles that a starting configuration is randomly selected from within the parameter space, the algorithm tests other configurations with the goal of finding the globally optimal solution, and the region from which new configurations can be selected shrinks as the search continues. The key difference between these algorithms is that in the SA algorithm, a single path, or trajectory, is taken in parameter space, from the starting point to the globally optimal solution, while in the RBSA algorithm, many trajectories are taken; by exploring multiple regions of the parameter space simultane-

ously, the algorithm has been shown to converge on the globally optimal solution about an order of magnitude faster than when using conventional algorithms.

Novel features of the RBSA algorithm include:

1. More efficient searching of the parameter space due to the branching structure, in which multiple random configurations are generated and multiple promising regions of the parameter space are explored;
2. The implementation of a trust region for each parameter in the parameter space, which provides a natural way of

enforcing upper- and lower-bound constraints on the parameters; and

3. The optional use of a constrained gradient-search optimization, performed on the continuous variables around each branch's configuration in parameter space to improve search efficiency by allowing for fast fine-tuning of the continuous variables within the trust region at that configuration point.

*This work was done by Matthew Bolcar, J. Scott Smith, and David Aronstein of Goddard Space Flight Center. Further information is contained in a TSP (see page 1). GSC-15908-1*

## Σ Method for Pre-Conditioning a Measured Surface Height Map for Model Validation

**This method can be implemented in most optical modeling and simulation software.**

*NASA's Jet Propulsion Laboratory, Pasadena, California*

This software allows one to up-sample or down-sample a measured surface map for model validation, not only without introducing any re-sampling errors, but also eliminating the existing measurement noise and measurement errors. Because the re-sampling of a surface map is accomplished based on the analytical expressions of Zernike-polynomials and a power spectral density model, such re-sampling does not introduce any aliasing and interpolation errors as is done by the conventional interpolation and FFT-based (fast-Fourier-transform-based) spatial-filtering method. Also, this new method automatically eliminates the measurement noise and other measurement errors such as artificial discontinuity.

The developmental cycle of an optical system, such as a space telescope, includes, but is not limited to, the following two steps: (1) deriving requirements or specs on the optical quality of individual optics before they are fabricated through optical modeling and simulations, and (2) validating the optical model using the measured surface

height maps after all optics are fabricated. There are a number of computational issues related to model validation, one of which is the "pre-conditioning" or pre-processing of the measured surface maps before using them in a model validation software tool.

This software addresses the following issues: (1) up- or down-sampling a measured surface map to match it with the gridded data format of a model validation tool, and (2) eliminating the surface measurement noise or measurement errors such that the resulted surface height map is continuous or smoothly-varying. So far, the preferred method used for re-sampling a surface map is two-dimensional interpolation. The main problem of this method is that the same pixel can take different values when the method of interpolation is changed among the different methods such as the "nearest," "linear," "cubic," and "spline" fitting in Matlab. The conventional, FFT-based spatial filtering method used to eliminate the surface measurement noise or measurement errors can also suffer from aliasing effects.

During re-sampling of a surface map, this software preserves the low spatial-frequency characteristic of a given surface map through the use of Zernike-polynomial fit coefficients, and maintains mid- and high-spatial-frequency characteristics of the given surface map by the use of a PSD model derived from the two-dimensional PSD data of the mid- and high-spatial-frequency components of the original surface map. Because this new method creates the new surface map in the desired sampling format from analytical expressions only, it does not encounter any aliasing effects and does not cause any discontinuity in the resultant surface map.

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

*The software used in this innovation is available for commercial licensing. Please contact Daniel Broderick of the California Institute of Technology at [danielb@caltech.edu](mailto:danielb@caltech.edu). Refer to NPO-47593.*