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(54) **METHOD AND APPARATUS FOR VEHICLE COMPONENT HEALTH PROGNOSIS BY INTEGRATING AGING MODEL, USAGE INFORMATION AND HEALTH SIGNATURES**

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G06N 15/18 (2006.01)

(52) **U.S. Cl.**
USPC **706/62**

(58) **Field of Classification Search** 706/62
See application file for complete search history.

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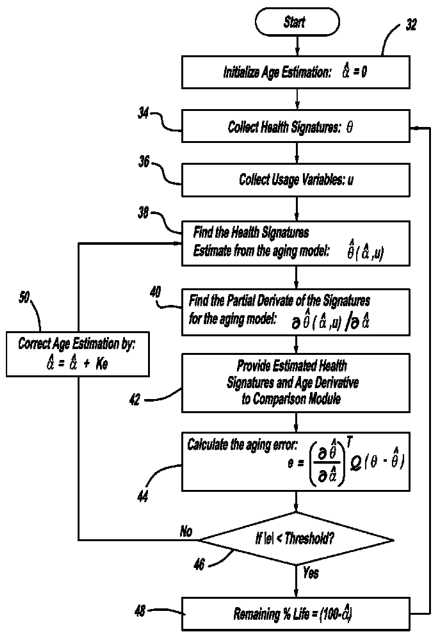
(57) **ABSTRACT**

A system and method for determining the health of a component includes retrieving measured health signatures from the component, retrieving component usage variables, estimating component health signatures using an aging model, determining an aging derivative using the aging model and calculating an aging error based on the estimated component health signatures, the aging derivative and the measured health signatures.

19 Claims, 3 Drawing Sheets



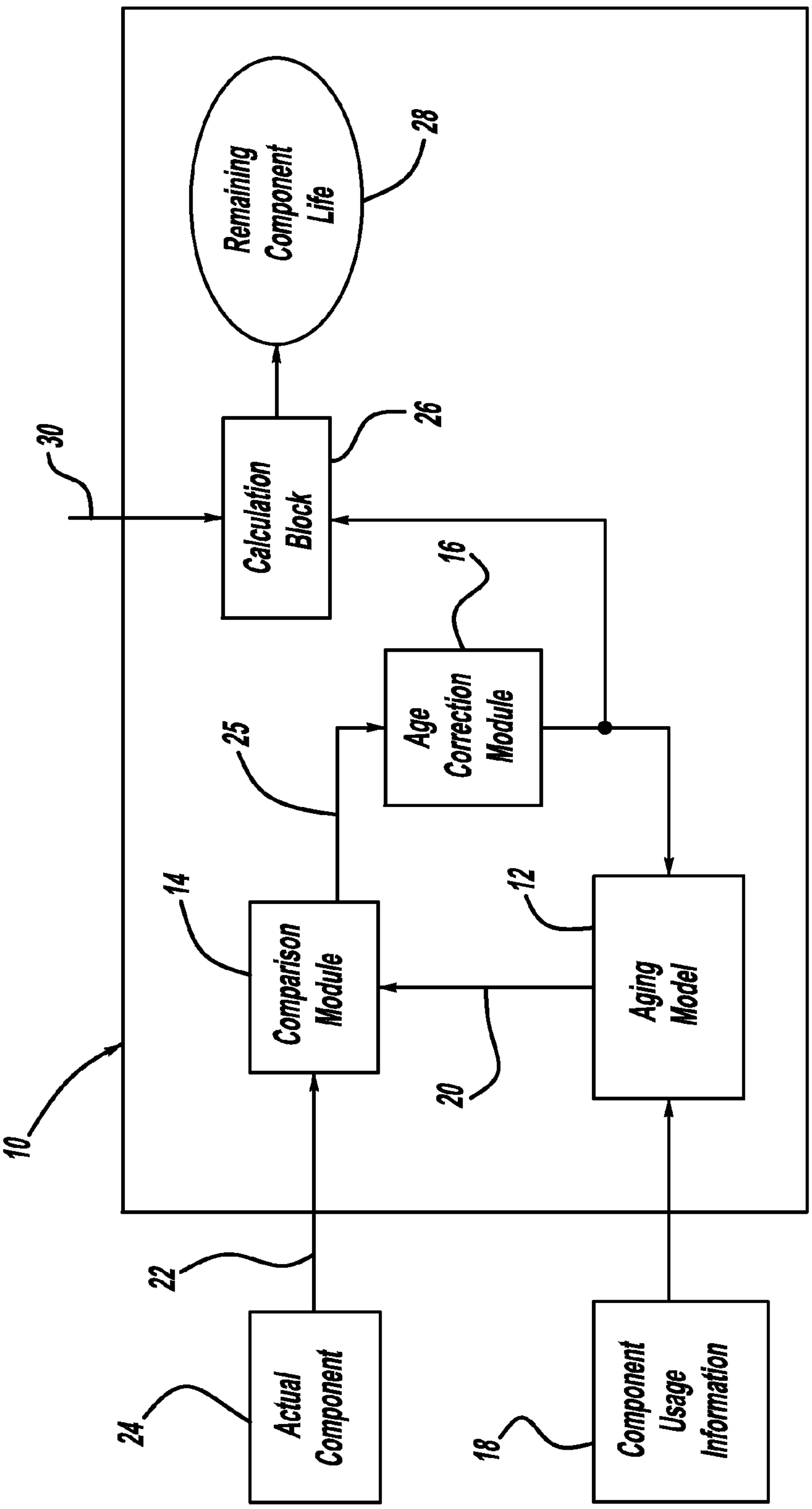

Remaining Component Life
28
30
Calculation Block
26
16
Age Correction Module
25
14
Comparison Module
12
Aging Model
20
10
22
Actual Component
24
Component Usage Information
18

FIG - 1

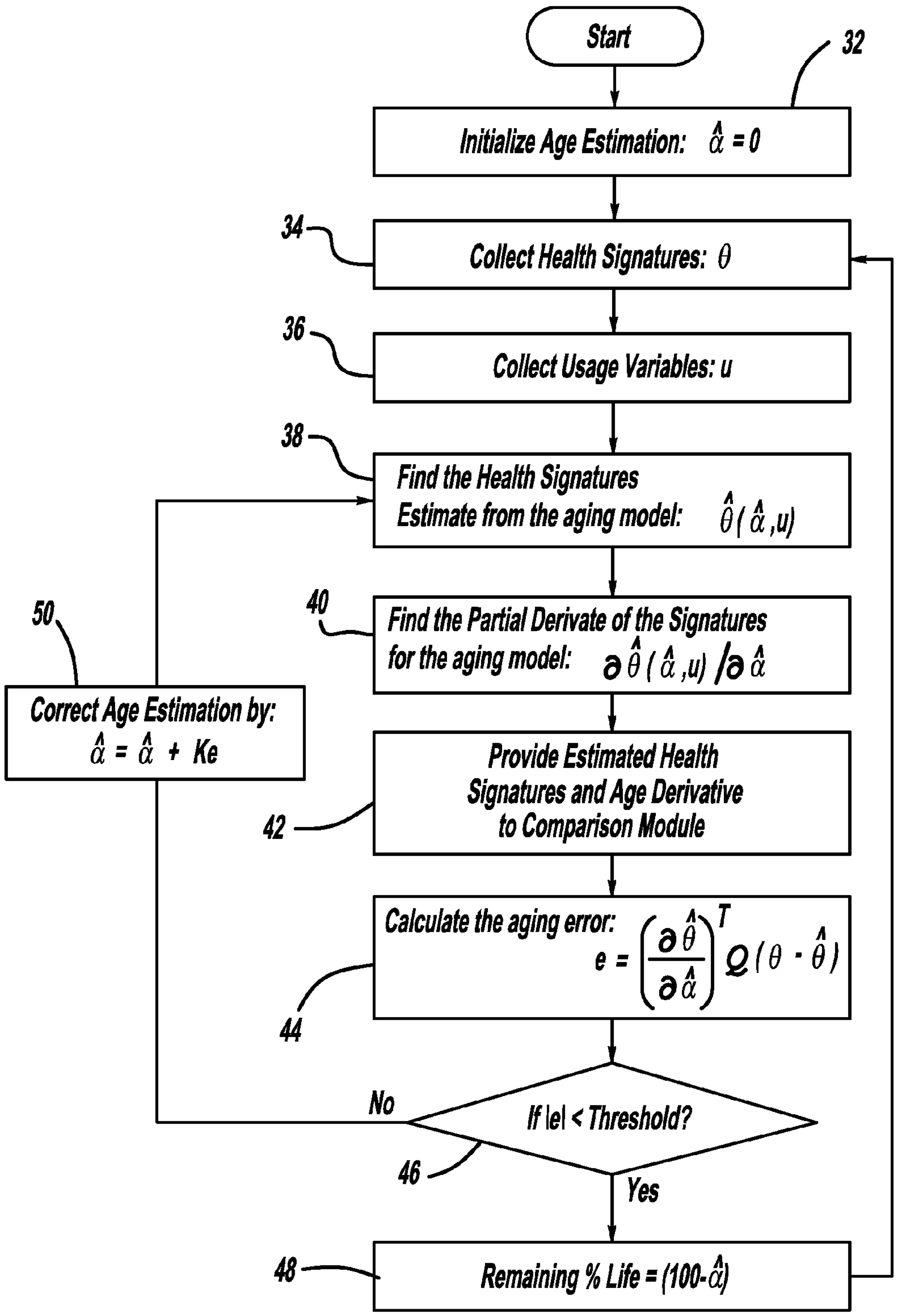

Start
32
Initialize Age Estimation: $\hat{\alpha} = 0$
34
Collect Health Signatures: θ
36
Collect Usage Variables: u
38
Find the Health Signatures
Estimate from the aging model: $\hat{\theta}(\hat{\alpha}, u)$
40
Find the Partial Derivate of the Signatures
for the aging model: $\partial \hat{\theta}(\hat{\alpha}, u) / \partial \hat{\alpha}$
50
Correct Age Estimation by:
$\hat{\alpha} = \hat{\alpha} + Ke$
42
Provide Estimated Health
Signatures and Age Derivative
to Comparison Module
Calculate the aging error:
$e = \left(\frac{\partial \hat{\theta}}{\partial \hat{\alpha}}\right)^T Q(\theta - \hat{\theta})$
44
No
If |e| < Threshold?
46
Yes
48
Remaining % Life = $(100-\hat{\alpha})$

FIG - 2

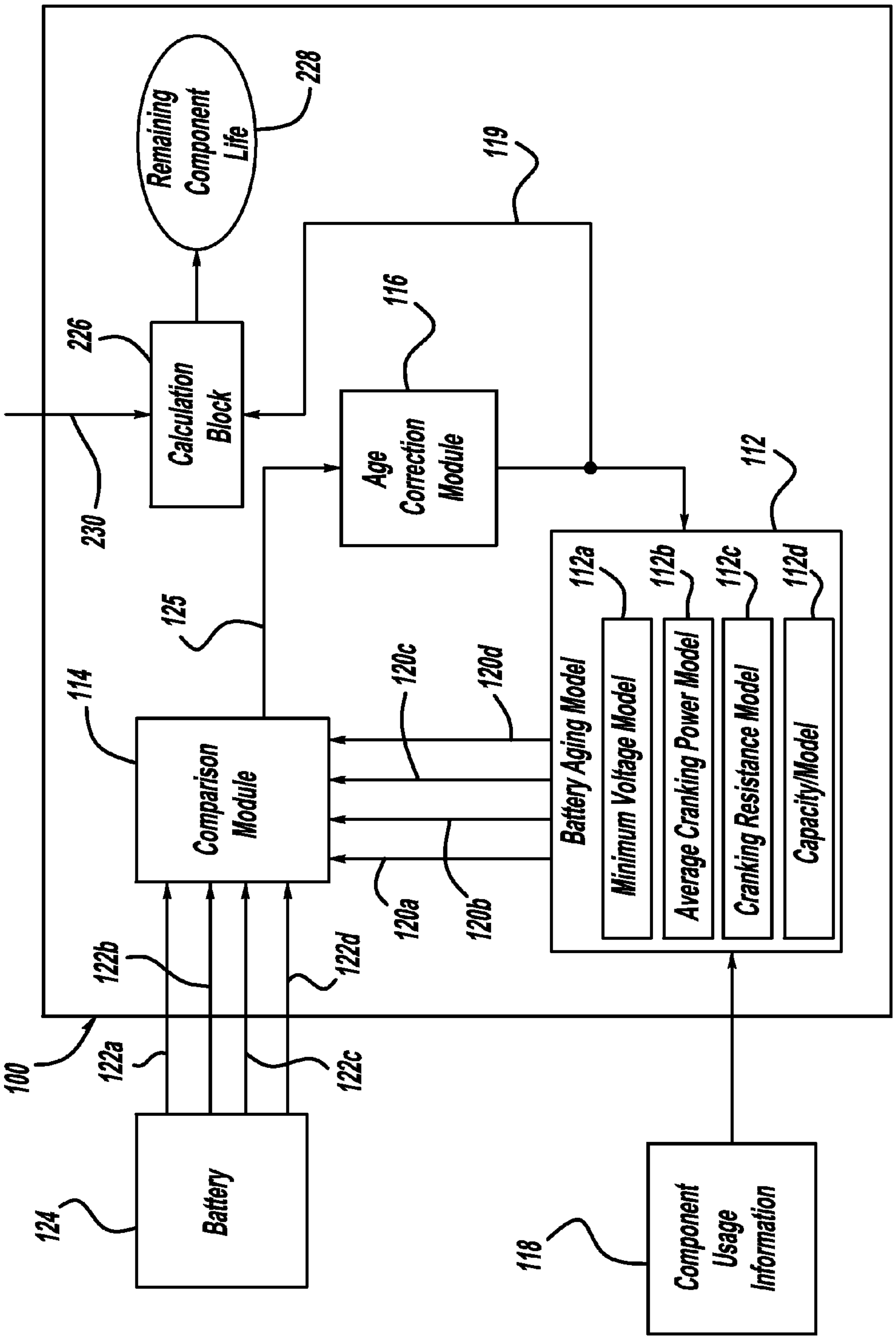

Remaining Component Life
228
119
226
Calculation Block
116
Age Correction Module
230
112
125
114
Comparison Module
120c
120d
120a
120b
Battery Aging Model
112a
112b
112c
112d
Minimum Voltage Model
Average Cranking Power Model
Cranking Resistance Model
Capacity/Model
122b
122d
100
122a
122c
124
Battery
118
Component Usage Information

FIG - 3

METHOD AND APPARATUS FOR VEHICLE COMPONENT HEALTH PROGNOSIS BY INTEGRATING AGING MODEL, USAGE INFORMATION AND HEALTH SIGNATURES

BACKGROUND

1. Field of the Invention

This invention relates generally to monitoring the state of health of vehicle components and, more particularly, to a component prognosis technique that utilizes the concept of an observer to integrate component health signatures, usage information and a degradation model.

2. Background

There is a constant effort in the automotive industry to improve the quality and reliability of vehicles by incorporating fault diagnosis and prognosis features into vehicles. One area of particular interest is the prognosis of individual vehicle components such as a battery or alternator. Several techniques have been developed that include monitoring a component's operating parameters, then applying an algorithm that compares the operating data to historical data to predict the behavior, age and remaining life of a component. These techniques, however, are one dimensional in that they don't integrate other factors that may contribute to the age and remaining life of a component.

Therefore, what is needed is a more robust and consistent multi-dimensional approach to component prognosis that utilizes the concept of an observer to integrate component health signatures, usage information and a degradation model.

SUMMARY

A system and method for determining the health of a component includes retrieving measured health signatures from the component, retrieving component usage variables, estimating component health signatures using an aging model, determining an aging derivative using the aging model and calculating an aging error based on the estimated component health signatures, the aging derivative and the measured health signatures.

Additional features of the present invention will become apparent from the following description and appended claims, taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** illustrates an exemplary component prognosis system, according to one embodiment; and

FIG. **2** is a flow chart illustrating an exemplary algorithm for determining the age and remaining life of a component according to the system of FIG. **1**; and

FIG. **3** illustrates the exemplary component prognosis system of FIG. **1**, wherein the component is a battery.

DETAILED DESCRIPTION OF THE EMBODIMENTS

The following discussion of the embodiments of the invention are directed a system and method for monitoring the health of vehicle components. The aforementioned embodiments are merely exemplary in nature, and are in no way intended to limit the invention, its applications or uses.

FIG. **1** illustrates an exemplary component prognosis system **10** for a vehicle. The system includes an aging model **12** in communication with both a comparison module **14** and an age correction module **16**. The aging model **12** is configured to receive component usage information **18** such as, but not limited to, component temperature, environmental conditions, power up times, power down times and length of use. The aging model **12** is also configured to receive an age estimation **19** from the age correction module **16**. The aging model **12**, also referred to as a degradation model, is a collection of one or more mathematical models used to determine the estimated age of a component. The mathematical models may include, but are not limited to, Arrhenius equations and Paris equations.

The aging model **12** is also configured to determine estimated component health signatures and age derivatives **20** based on the component usage information **18**. In general, a component health signature refers to a component specific characteristic that describes the functionality of the component. In one non-limiting example, a component health signature may be a component's voltage, current, capacitance or resistance. An age derivative is the change of the component health signature with respect to the change of the age. The estimated component health signatures and age derivatives generated by the aging model **12** are input to the comparison module **14**.

The comparison module **14** is configured to receive and compare measured component health signatures **22** from the actual component **24** to the estimated component health signatures **20** from the aging model **12**. The comparison also includes calculating an aging error **25** using the measured component health signatures **22** and the estimated component health signatures **20**. In one embodiment, the age error is calculated using an equation, such as:

$$e = \left(\frac{\partial \hat{\theta}}{\partial \hat{\alpha}}\right)^T Q(\theta - \hat{\theta}) \tag{1}$$

where θ is the vector of measured component health signatures **22**, $\hat{\theta}$ is the vector estimated component health signatures **20**, $\hat{\alpha}$ is the age estimation **19**, $(\partial\hat{\theta}/\partial\hat{\alpha})$ indicates the age derivative, and Q is a matrix indicating weighting factor of different signatures and T represents the transpose of a matrix.

In this example, equation (1) is the derivative of the cost function in equation (2) with respect to the age estimation.

$$J = \frac{1}{2}(\theta - \hat{\theta})^T Q(\theta - \hat{\theta}) \tag{2}$$

However, as understood by one of ordinary skill in the art, any suitable algorithm or equation may be used to calculate the age error including, but not limited to, a fusion algorithm or fuzzy logic.

Based on the value of the age error **25**, the component age estimation is corrected using the age correction module **16**, which adjusts the previously estimated age of the component using the calculated age error value. Equation (3) below illustrates an exemplary equation for correcting the age estimation where $\hat{\alpha}$ is the estimated age and K represents a gain.

$$\hat{\alpha} = \hat{\alpha} + Ke \tag{3}$$

When the value of the age error **25** is sufficiently low, the age estimation is sent to calculation block **26** where a percentage of remaining component life **28** is calculated using a maximum life expectancy value **30** for that specific component.

FIG. **2** is a flow chart illustrating an exemplary algorithm **10** for determining the age and remaining life of a component according to the system of FIG. **1**. At step **32**, the age estimation $\hat{\alpha}$ for the aging model **12** is initialized to zero indicating a new component. At steps **34** and **36**, respectively, the health signatures θ from the actual component **24** and the usage variables u from the component usage information **18** are collected. At step **38**, the aging model **12** determines the estimated health signatures $\hat{\theta}$ a using particular aging model, which in this example, is given by:

$$\hat{\theta}(\hat{\alpha},u) \tag{4}$$

where the estimated health signatures $\hat{\theta}$ is a function of $\hat{\alpha}$ and u.

At step **40**, the aging model **12** determines the age derivative of the health signatures, which in this example, is given by:

$$\partial\hat{\theta}(\hat{\alpha},u)/\partial\hat{\alpha} \tag{5}$$

At step **42**, the estimated health signatures and the age derivatives **20** from the aging model **12** are provided to the comparison module **14**. At step **44**, the comparison module **14** calculates the aging error **25** using equation (1). At step **46** the calculated aging error is compared to a threshold in the age correction module **16**. If the aging error is less than the threshold, the remaining component life, which is generally given as a percentage, is calculated at step **48** and the process returns to step **34** to continually re-evaluate the age of the component. If the aging error is not less than the threshold, at step **50** the age correction module **16** calculates an age correction using equation (3) above. Once the corrected age is determined, the process continues at step **38** until the aging error is minimized to a level below the threshold.

FIG. **3** illustrates an exemplary component prognosis system **100**, similar to FIG. **1**, wherein the component is a battery. The system includes an aging model **112** in communication with both a comparison module **114** and an age correction module **116**. The aging model **112** is configured to determine the estimated component health signatures and age derivatives **120** based on the component usage information **118**, which in this case may be the battery temperature, state of charge and other environmental conditions. In this example, the aging model **112** includes a minimum voltage model **112***a*, an average cranking power voltage model **112***b*, a cranking resistance model **112***c* and a capacity model **112***d*. These models, respectively, are used to calculate the estimated values for minimum voltage **120***a*, average power **120***b*, cranking resistance **120***c* and reserve capacity **120***d*.

The comparison module **114** is configured to receive and compare the measured component health signatures **122** from the battery **124** to the estimated component health signatures **120***a-d* from the aging model **112**. In this example, the measured component health signatures **122** include minimum voltage **122***a*, average power **122***b*, cranking resistance **122***c* and reserve capacity **122***d*. The comparison also includes calculating an aging error **125** using the measured component health signatures **122** and the estimated component health signatures **120**.

Like the system of FIG. **1**, based on the value of the age error **125**, the component age estimation is corrected using the age correction module **116**, which adjusts the previously estimated age of the component using the calculated age error value. When the value of the age error **125** is sufficiently low, the age estimation **119** is sent to calculation block **226** where a percentage of remaining component life **228** is calculated using age estimation and a maximum life expectancy value **230** for that specific component.

The system described herein may be implemented on one or more suitable computing devices, which generally include applications that may be software applications tangibly embodied as a set of computer-executable instructions on a computer readable medium within the computing device. The computing device may be any one of a number of computing devices, such as a personal computer, processor, handheld computing device, etc.

Computing devices generally each include instructions executable by one or more devices such as those listed above. Computer-executable instructions may be compiled or interpreted from computer programs created using a variety of programming languages and/or technologies, including without limitation, and either alone or in combination, Java™, C, C++, Visual Basic, Java Script, Perl, etc. In general, a processor (e.g., a microprocessor) receives instructions, e.g., from a memory, a computer-readable medium, etc., and executes these instructions, thereby performing one or more processes, including one or more of the processes described herein. Such instructions and other data may be stored and transmitted using a variety of known computer-readable media.

A computer-readable media includes any medium that participates in providing data (e.g., instructions), which may be read by a computing device such as a computer. Such a medium may take many forms, including, but not limited to, non-volatile media, volatile media, and transmission media. Non-volatile media includes, for example, optical or magnetic disks and other persistent memory. Volatile media include dynamic random access memory (DRAM), which typically constitutes a main memory. Common forms of computer-readable media include any medium from which a computer can read.

It is to be understood that the above description is intended to be illustrative and not restrictive. Many alternative approaches or applications other than the examples provided would be apparent to those of skill in the art upon reading the above description. The scope of the invention should be determined, not with reference to the above description, but should instead be determined with reference to the appended claims, along with the full scope of equivalents to which such claims are entitled. It is anticipated and intended that further developments will occur in the arts discussed herein, and that the disclosed systems and methods will be incorporated into such further examples. In sum, it should be understood that the invention is capable of modification and variation and is limited only by the following claims.

The present embodiments have been particular shown and described, which are merely illustrative of the best modes. It should be understood by those skilled in the art that various alternatives to the embodiments described herein may be employed in practicing the claims without departing from the spirit and scope of the invention and that the method and system within the scope of these claims and their equivalents be covered thereby. This description should be understood to include all novel and non-obvious combinations of elements described herein, and claims may be presented in this or a later application to any novel and non-obvious combination of these elements. Moreover, the foregoing embodiments are illustrative, and no single feature or element is essential to all possible combinations that may be claimed in this or a later application.

All terms used in the claims are intended to be given their broadest reasonable construction and their ordinary meaning as understood by those skilled in the art unless an explicit indication to the contrary is made herein. In particular, use of the singular articles such as "a", "the", "said", etc. should be read to recite one or more of the indicated elements unless a claim recites an explicit limitation to the contrary.

What is claimed is:

1. A method for determining the health of a component, the method comprising:

retrieving measured health signatures from the component;

retrieving component usage variables;

estimating component health signatures using an aging model and the component usage variables;

determining an aging derivative using the aging model;

calculating an aging error based on the estimated component health signatures, the aging derivative and the measured health signatures; and

recalculating the estimated component health signatures and the aging derivative until the aging error is below a predetermined threshold.

2. The method of claim **1**, further including calculating a corrected age of the component based on an estimated age and the aging error.

3. The method of claim **1**, further including determining if the aging error is below a predetermined threshold.

4. The method of claim **3**, further including calculating a remaining life of the component if the aging error is below the predetermined threshold.

5. The method of claim **1**, further including initializing the estimated component age to zero.

6. The method of claim **1**, further including calculating an estimated age of the component based on the aging error.

7. A system for determining the health of a component, the system comprising:

a computing device with a memory that includes:

an aging model configured to calculate estimated component health signatures based on a plurality of component usage variables;

a comparison module configured to calculate an aging error based on the estimated component health signatures and measured component health signatures; and

a calculation block configured to calculate an estimated age of the component based on the aging error, and to determine the remaining life of the component based on a maximum life expectancy and the estimated age of the component.

8. The system of claim **7**, further including an aging correction module configured to calculate a corrected age of the component based on an estimated age and the aging error.

9. The method of claim **7**, wherein the aging model and the comparison module are configured to recalculate, respectively, the estimated component health signatures and the aging derivative until the aging error is below a predetermined threshold.

10. A system that includes a non-transitory computer-readable medium tangibly embodying computer-executable instructions for:

initializing an age estimation;

retrieving measured health signatures from the component;

retrieving component usage variables;

estimating component health signatures using the age estimation and the component usage variables;

determining an aging derivative using the partial derivative of the estimated health signature with respect to the age estimation; and

calculating an aging error based on the estimated component health signatures, the aging derivative and the measured health signatures.

11. The system of claim **10**, further including calculating a corrected age of the component based on the age estimation and the aging error.

12. The system of claim **10**, further including determining if the aging error is below a predetermined threshold.

13. The system of claim **12**, further including calculating a remaining life of the component if the aging error is below the predetermined threshold.

14. The system of claim **10**, further including recalculating the estimated component health signatures and the aging derivative until the aging error is below a predetermined threshold.

15. The system of claim **10**, further including initializing the age estimation to zero.

16. The system of claim **10**, further including revising the age estimation based on the aging error.

17. The system of claim **10**, where estimating component health signatures using the age estimation and the component usage variables uses an aging model.

18. The system of claim **17**, where determining an aging derivative using the partial derivative of the estimated health signature with respect to the age estimation uses the ageing model.

19. The system of claim **10**, where determining an aging derivative using the partial derivative of the estimated health signature with respect to the age estimation uses an ageing model.

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