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(54) SYSTEM AND METHOD FOR AUTONOMOUS ACTUATION OF SAFETY CONTROL SYSTEM COMPONENTS

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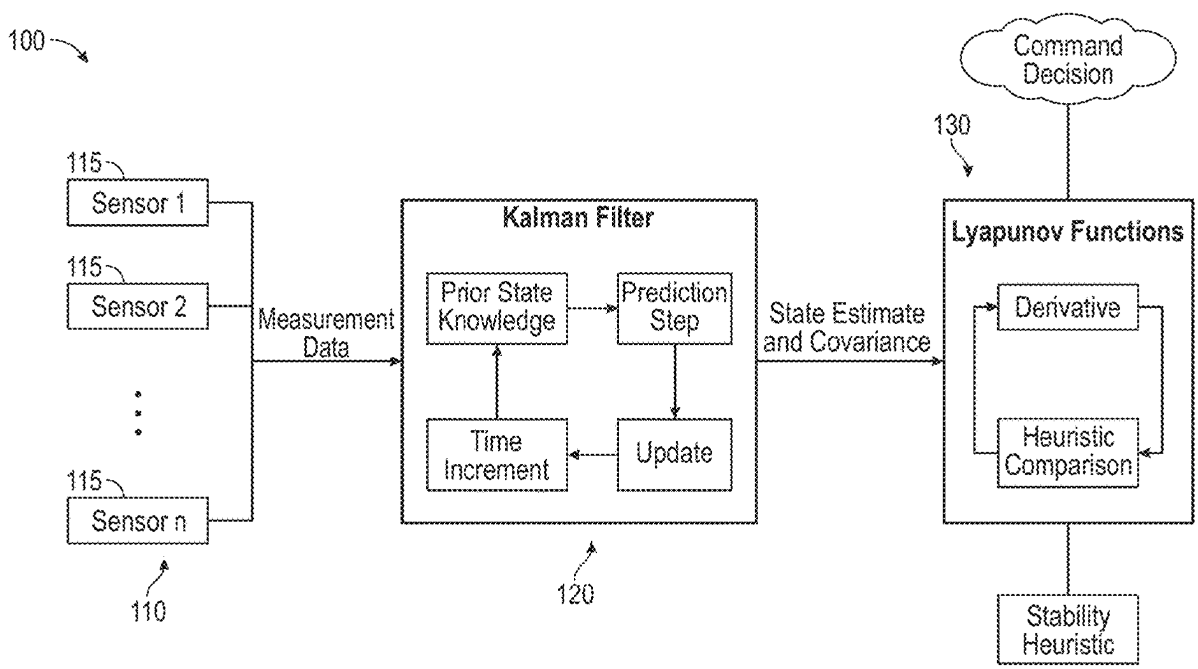
(57) **ABSTRACT**

A system for actuating a safety control for a device including: (1) at least one sensor adapted to measure a parameter of the device and provide an output; (2) a Kalman filter adapted to receive the output of the at least one sensor and provide a state estimate and covariance value of the device; (3) a Lyapunov function adapted to receive the state estimate and covariance value from the Kalman filter and provide a time derivative; and (4) a comparator adapted to compare the time derivative to a reference value and provide a command decision to the device.



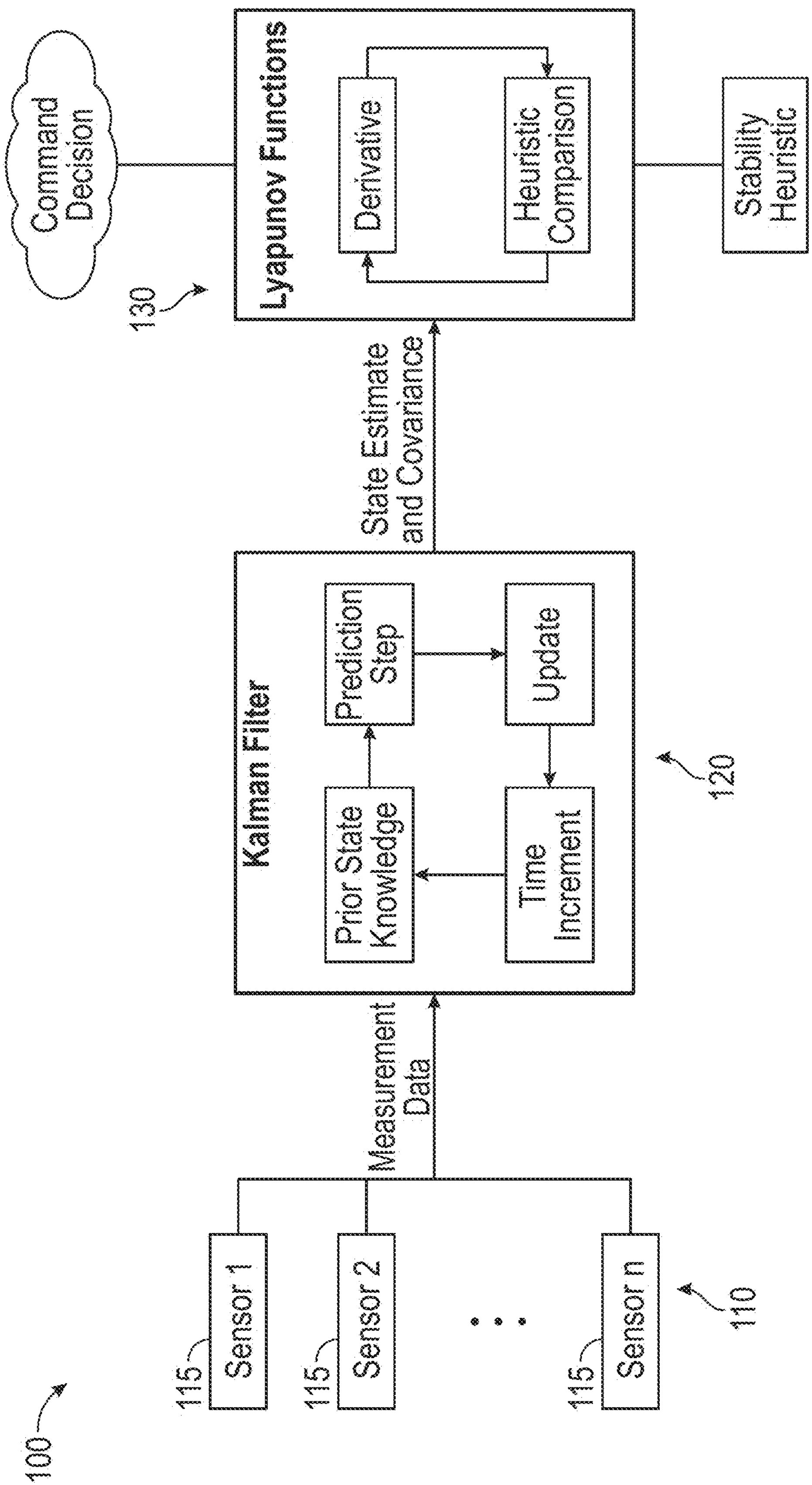

100
115
Sensor 1
115
Sensor 2
115
Sensor n
110
Measurement Data
Kalman Filter
Prior State Knowledge
Prediction Step
Update
Time Increment
120
State Estimate and Covariance
Lyapunov Functions
Derivative
Heuristic Comparison
130
Command Decision
Stability Heuristic

FIG. 1

SYSTEM AND METHOD FOR AUTONOMOUS ACTUATION OF SAFETY CONTROL SYSTEM COMPONENTS

RELATED APPLICATIONS

[0001] This application claims priority under 35 U.S.C. § 119 (e) of U.S. Provisional Patent Application Ser. No. 63/555,948 (Attorney Docket No. 1949.00023) filed on Feb. 21, 2024 and titled SYSTEM AND METHOD FOR AUTONOMOUS ACTUATION OF SAFETY CONTROL SYSTEM COMPONENTS. The content of this application is incorporated herein by reference.

FIELD OF THE INVENTION

[0002] The present invention relates to systems and methods for monitoring and actuating safety control systems.

BACKGROUND OF THE INVENTION

[0003] Known control systems utilize a standard threshold trigger and action, which require that a threshold be reached before mitigation techniques may be used. This results in longer delay before mitigation techniques may be utilized when compared to systems that are able to predict when a device is likely to reach the threshold. Therefore, a need exists for a control system that calculates the likelihood of a threshold being reached and takes action based on the likelihood of reaching the threshold or speed at which the threshold is being approached.

[0004] This background information is provided to reveal information believed by the applicant to be of possible relevance to the present invention. No admission is necessarily intended, nor should be construed, that any of the preceding information constitutes prior art against the present invention.

SUMMARY OF THE INVENTION

[0005] With the above in mind, embodiments of the present invention are related to a system for actuating a safety control for a device. The system may include at least one sensor, a Kalman filter, a Lyapunov function, and a comparator.

[0006] The at least one sensor may be adapted to measure a parameter of the device and provide an output.

[0007] The Kalman filter may be adapted to receive the output of the at least one sensor and provide a state estimate and covariance value of the device.

[0008] The Lyapunov function may be adapted to receive the state estimate and covariance value from the Kalman filter and provide a time derivative.

[0009] The comparator may be adapted to compare the time derivative to a reference value and provide a command decision to the device.

[0010] The output may include measured noise.

[0011] The command decision may initiate a mitigation strategy.

[0012] The comparator may compare the time derivative to the reference value only if the time derivative is positive.

[0013] The at least one sensor may include a plurality of sensors.

[0014] In one embodiment, the system may include the device.

[0015] In one embodiment, the device may include a braking system. In such an embodiment, the command decision may initiate a safe braking operation of the device.

[0016] In one embodiment, the device may include a mobile explosive device. In such a device, the command decision may initiate a self-destruct operation of the device.

[0017] In one embodiment, the system may include a first sensor adapted to measure a first performance parameter of the device and provide a first output and a second sensor adapted to measure a second performance parameter of the device and provide a second output.

[0018] In such an embodiment, the first output may include a first measured noise and the second output may include a second measured noise.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019] Some embodiments of the present invention are illustrated as an example and are not limited by the figures of the accompanying drawings, in which like references may indicate similar elements.

[0020] FIG. **1** is a block diagram of the system for actuation of a safety control system according to one embodiment of the invention.

DETAILED DESCRIPTION OF THE INVENTION

[0021] The present invention will now be described more fully hereinafter with reference to the accompanying drawings, in which preferred embodiments of the invention are shown. This invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. Those of ordinary skill in the art realize that the following descriptions of the embodiments of the present invention are illustrative and are not intended to be limiting in any way. Other embodiments of the present invention will readily suggest themselves to such skilled persons having the benefit of this disclosure. Like numbers refer to like elements throughout.

[0022] Although the following detailed description contains many specifics for the purposes of illustration, anyone of ordinary skill in the art will appreciate that many variations and alterations to the following details are within the scope of the invention. Accordingly, the following embodiments of the invention are set forth without any loss of generality to, and without imposing limitations upon, the claimed invention.

[0023] In this detailed description of the present invention, a person skilled in the art should note that directional terms, such as "above," "below," "upper," "lower," and other like terms are used for the convenience of the reader in reference to the drawings. Also, a person skilled in the art should notice this description may contain other terminology to convey position, orientation, and direction without departing from the principles of the present invention.

[0024] Furthermore, in this detailed description, a person skilled in the art should note that quantitative qualifying terms such as "generally," "substantially," "mostly," and other terms are used, in general, to mean that the referred to object, characteristic, or quality constitutes a majority of the subject of the reference. The meaning of any of these terms is dependent upon the context within which it is used, and the meaning may be expressly modified.

[0025] An embodiment of the invention, as shown and described by the various FIGURES and accompanying text, provides a system and method for actuation of a safety control system. The inventive method provides for the actuation of a safety control system using blended sensor fusion and error residuals to determine if the system is operating outside of the prescribed safety requirements. This system can be used to make positive safety determinations for in situ autonomous systems, including, by way of example, and not as a limitation, hypersonic missiles, torpedoes, safety braking systems, and the like, should the autonomous system veer from its intended target or control point. The method may also be utilized to identify anomalous behavior of system components to enable early detection, which allows for non-destructive mitigation strategies, including, but not limited to, safe stopping of a locomotive if the system state exceeds a pre-determined operational boundary.

[0026] The system for actuation of a safety control system **100** may include a multiple sensor redundant system **110**. The multiple sensor redundant system **110** may include a plurality of complexes of sensors to derive an aggregated state of the system. The specific type of sensors **115** included within each of the complexes of sensors may depend upon the application in which the complex of sensors is utilized. The aggregated state of the system provided by the multiple sensor redundant system **110** may be provided to a Kalman filter **120**. The Kalman filter **120** may include an algorithm that utilizes a plurality of measurements received from one or more of the sensors **115** over time. The measurements from the one or more sensors **115** may include statistical noise and other inaccuracies. The algorithm may utilize one or more of these measurements to produce an estimate of one or more unknown variables by estimating a joint probability distribution over the one or more variables for each time-step. The Kalman filter **120** may utilize the aggregated state of the system data to determine the probabilistic state of the system being monitored.

[0027] The Kalman filter **120** may serve at least two purposes. First, it may homogenize the sensor measurement data received from the multiple sensor redundant system **110** into a common coordinate system or domain by performing linear translation between the native system and the intended system. Second, it may combine the measurement information from the multiple sensor redundant system **110** into a best state estimate and associated covariance. In one embodiment, the conversion may utilize prior state knowledge and methods of weighting. A resulting state estimate and associated Gaussian covariance matrix may be output by the Kalman filter **120** and provided to Lyapunov functions **130**.

[0028] Stability heuristics may be determined a priori, based upon the system intent, to determine a reference value. The reference value may be compared to the probabilistic state and covariance estimate provided by the Lyapunov functions. If the time derivative of the comparison to the Lyapunov function value tends toward equilibrium, it is a negative value. If the time derivative is positive, it is heading away from equilibrium. The rate at which the system is moving from equilibrium affords the opportunity to mitigate a system operation. In when embodiment, a system operation may be mitigated if the rate of movement away from equilibrium exceeds an acceptable rate, which may be the reference value or may be related to the reference value. This is in contrast to the known method of control systems, which utilize a standard threshold trigger and action, which results in a longer delay before mitigation techniques may be utilized.

[0029] An additional benefit of processing both the state estimate and associated covariance through the Lyapunov function is an understanding of the temporal stability of both the system state and the system error. The trend of the system state covariance as determined by the Lyapunov function indicates the decision-making quality of the control algorithm itself. This quality metric may be used to check the validity of input measurement data, filter parameters or residuals, or other salient input criteria.

[0030] The inventive method can be used not only to make a positive control decision regarding an in-situ system, but also to evaluate the quality of the decision itself.

[0031] In one embodiment, the Kalman Filter **120** or Lyapunov filter **130** may be implemented by a general purpose processing unit. In one embodiment, a general purpose processing unit may compare the output of the Lyapunov filter **130** to the reference value and provide the command decision.

[0032] Some of the illustrative aspects of the present invention may be advantageous in solving the problems herein described and other problems not discussed which are discoverable by a skilled artisan.

[0033] While the above description contains much specificity, these should not be construed as limitations on the scope of any embodiment, but as exemplifications of the presented embodiments thereof. Many other ramifications and variations are possible within the teachings of the various embodiments. While the invention has been described with reference to exemplary embodiments, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the invention. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the invention without departing from the essential scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiment disclosed as the best or only mode contemplated for carrying out this invention, but that the invention will include all embodiments falling within the scope of the appended claims. Also, in the drawings and the description, there have been disclosed exemplary embodiments of the invention and, although specific terms may have been employed, they are unless otherwise stated used in a generic and descriptive sense only and not for purposes of limitation, the scope of the invention therefore not being so limited. Moreover, the use of the terms first, second, etc. do not denote any order or importance, but rather the terms first, second, etc. are used to distinguish one element from another. Furthermore, the use of the terms a, an, etc. do not denote a limitation of quantity, but rather denote the presence of at least one of the referenced item.

[0034] Thus the scope of the invention should be determined by the appended claims and their legal equivalents, and not by the examples given.

What is claimed is:

1. A system for actuating a safety control for a device comprising:

at least one sensor adapted to measure a parameter of the device and provide an output;

a Kalman filter adapted to receive the output of the at least one sensor and provide a state estimate and covariance value of the device;

a Lyapunov function adapted to receive the state estimate and covariance value from the Kalman filter and provide a time derivative; and

a comparator adapted to compare the time derivative to a reference value and provide a command decision to the device.

2. The system of claim **1** wherein the output includes measured noise.

3. The system of claim **1** wherein the command decision initiates a mitigation strategy.

4. The system of claim **1** wherein the comparator compares the time derivative to the reference value only if the time derivative is positive.

5. The system of claim **1** wherein the at least one sensor includes a plurality of sensors.

6. The system of claim **1** further comprising the device.

7. The system of claim **5** wherein the device further comprises a braking system.

8. The system of claim **6** wherein the command decision initiates a safe braking operation of the device.

9. The system of claim **5** wherein the device further comprises a mobile explosive device.

10. The system of claim **8** wherein the command decision initiates a self-destruct operation of the device.

11. A system for actuating a safety control for a device comprising:

a first sensor adapted to measure a first performance parameter of the device and provide a first output;

a second sensor adapted to measure a second performance parameter of the device and provide a second output;

a Kalman filter adapted to receive the first output of the first sensor and the second output of the second sensor and provide a state estimate and covariance value of the device;

a Lyapunov function adapted to receive the state estimate and covariance value from the Kalman filter and provide a time derivative; and

a comparator adapted to compare the time derivative to a reference value and provide a command decision to the device.

12. The system of claim **11** wherein the first output includes a first measured noise and the second output includes a second measured noise.

13. The system of claim **10** further comprising the device.

14. The system of claim **8** wherein the device further comprises a braking system.

15. The system of claim **12** wherein the command decision initiates a safe braking operation of the device.

16. The system of claim **11** wherein the device further comprises a mobile explosive device.

17. The system of claim **15** wherein the command decision initiates a self-destruct operation of the device.

18. A system for actuating a safety control for a device comprising:

the device;

a first sensor adapted to measure a first performance parameter of the device and provide a first output including a first measured noise;

a second sensor adapted to measure a second performance parameter of the device and provide a second output including a second measure noise;

a Kalman filter adapted to receive the first output of the first sensor and the second output of the second sensor and provide a state estimate and covariance value of the device;

a Lyapunov function adapted to receive the state estimate and covariance value from the Kalman filter and provide a time derivative; and

a comparator adapted to compare the time derivative to a reference value and provide a command decision to the device.

19. The system of claim **18** wherein the device comprises a braking system and the command decision initiates a safe braking operation of the device.

20. The system of claim **18** wherein the device comprises a mobile explosive device and the command decision initiates a self-destruct operation of the device.

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