UNSUPERVISED ANOMALY DETECTION FOR AUTONOMOUS VEHICLES

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is based on U.S. Application No. 16/887,194, filed May 29, 2020, which claims priority to U.S. Provisional Application No. 62/900,380, filed September 13, 2019, the contents both of which are hereby incorporated by reference for all purposes.

TECHNICAL FIELD

[0002] This disclosure relates generally to detecting anomalies in time series data, and in particular but not exclusively, relates to detecting anomalies in telemetry information from autonomous vehicles.

BACKGROUND INFORMATION

[0003] As aerial robots become increasingly capable of complex navigation, perceptual reasoning and ability to learn from experience, it is expected that a large number of delivery missions will soon be executed by small air-vehicles taking off autonomously, flying far beyond line of sight over densely populated areas, hovering inside a residential zone within touching distance of humans to deliver the package, and returning to their "home" upon mission completion. Ensuring as high degree of operational reliability and safety as passenger airplanes is critical for delivery drones to achieve economies of scale.

SUMMARY OF INVENTION

[0004] In some embodiments, a non-transitory computer-readable medium is provided. The computer-readable medium has logic stored thereon that, in response to execution by one or more processors of a computing system, cause the computing system to perform actions for detecting anomalies in time series data records. The actions comprise ~~receiving, by the computing system, a plurality of time series data records; initializing, by the computing system, a machine learning model having a set of fitting weights and a set of time series data record weights; optimizing, by the computing system, the set of fitting weights of the machine learning model while~~

receiving, by the computing system, a plurality of time series data records, wherein the plurality of time series data records includes at least one anomalous time series data record; initializing, by the computing system, a machine learning model having a set of fitting weights and a set of time series data record weights; optimizing, by the computing system, the set of fitting weights of the machine learning model using the plurality of time series data records while holding the set of time series data record weights of the machine learning model constant, wherein optimizing the set of fitting weights using the plurality of time series data records includes using the time series data record weights to identify one or more anomalous time series data records of the plurality of time series data records to be ignored during optimization; optimizing, by the computing system, the set of time series data record weights while holding the set of fitting weights constant; repeating, by the computing system, the optimizing the set of fitting weights after the optimizing the set of time series data record weights at least one time; and storing, by the computing system, the optimized time series data record weights and the optimized fitting weights for use in monitoring for anomalies~~holding the set of trip weights of the machine learning model constant; optimizing, by the computing system, the set of time series data record weights while holding the set of fitting weights constant; and storing, by the computing system, the optimized time series data record weights and the optimized fitting weights for use in monitoring for anomalies~~.

[0005] In some embodiments, a method of detecting and addressing anomalies in autonomous vehicle telemetry data is provided. ~~for detecting anomalies in time series data records is provided. A computing device receives a time series data record from a monitored system. The computing device processes the time series data record using a machine learning model to generate an anomaly score, wherein the machine learning model was trained on a plurality of previous time series data records. The computing device compares the anomaly score to an anomaly threshold value. In response to determining that the anomaly score is greater than the anomaly threshold value the computing device determines an action to be taken to address the anomaly and transmits a command to the monitored system to cause the monitored system to perform the action to address the anomaly .~~The method comprises initializing, by a computing system, a set of fitting weights for a machine learning model, wherein the fitting weights are used by the machine learning model to

determine anomaly scores for new time series data records; initializing, by the computing system, a set of time series data record weights associated with a training data set, wherein each time series data record weight is associated with a time series data record of a plurality of time series data records in the training data set, and wherein the time series data record weights are usable to identify one or more anomalous time series data records of the training data set to be ignored during optimization of the set of fitting weights; training, by the computing system, the machine learning model by alternating at least two times between using the set of time series data record weights while optimizing the set of fitting weights based on the training data set, and using the set of fitting weights while optimizing the set of time series data record weights, wherein using the set of time series data record weights while optimizing the set of fitting weights includes ignoring at least one of the plurality of time series data records in the training data set based on the time series data record weights; and storing, by the computing system, the optimized time series data record weights and the optimized fitting weights for use in monitoring for anomalies.

[0006] In some embodiments, a system is provided. The system comprises a computing system ~~at least one computing device that includes at least one processor a non-transitory computer-readable medium. The computer-readable medium has logic stored thereon that, in response to execution by the at least one processor, causes the system to perform actions comprising: receiving a time series data record from a monitored system; processing the time series data record using a machine learning model to generate an anomaly score, wherein the machine learning model was trained on a plurality of previous time series data records; comparing the anomaly score to an anomaly threshold value; and in response to determining that the anomaly score is greater than the anomaly threshold value: determining an action to be taken to address the anomaly; and transmitting a command to the monitored system to cause the monitored system to perform the action to address the anomaly~~ having at least one computing device that includes at least one processor and a non-transitory computer-readable medium having logic stored thereon that, in response to execution by the at least one processor, causes the computing system to perform actions comprising ~~:~~ initializing, by the computing system, a set of fitting weights for a machine learning model, wherein the fitting weights are used by the machine learning model to

determine anomaly scores for new time series data records; initializing, by the computing system, a set of time series data record weights associated with a training data set, wherein each time series data record weight is associated with a time series data record of a plurality of time series data records in the training data set, and wherein the time series data record weights are usable to identify one or more anomalous time series data records of the training data set to be ignored during optimization of the set of fitting weights; training, by the computing system, the machine learning model by alternating at least two times between using the set of time series data record weights while optimizing the set of fitting weights based on the training data set, and using the set of fitting weights while optimizing the set of time series data record weights, wherein using the set of time series data record weights while optimizing the set of fitting weights includes ignoring at least one of the plurality of time series data records in the training data set based on the time series data record weights; and storing, by the computing system, the optimized time series data record weights and the optimized fitting weights for use in monitoring for anomalies.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] Non-limiting and non-exhaustive embodiments of the invention are described with reference to the following figures, wherein like reference numerals refer to like parts throughout the various views unless otherwise specified. Not all instances of an element are necessarily labeled so as not to clutter the drawings where

CLAIMS

What is claimed is:

1. A non-transitory computer-readable medium having logic stored thereon that, in response to execution by one or more processors of a computing system, cause the computing system to perform actions for detecting anomalies in time series data records, the actions comprising:

receiving, by the computing system, a plurality of time series data records, wherein the plurality of time series data records includes at least one anomalous time series data record;

initializing, by the computing system, a machine learning model having a set of fitting weights and a set of time series data record weights;

optimizing, by the computing system, the set of fitting weights of the machine learning model using the plurality of time series data records while holding the set of ~~trip~~ time series data record weights of the machine learning model constant, wherein optimizing the set of fitting weights using the plurality of time series data records includes using the time series data record weights to identify one or more anomalous time series data records of the plurality of time series data records to be ignored during optimization;

optimizing, by the computing system, the set of time series data record weights while holding the set of fitting weights constant;

repeating, by the computing system, the optimizing the set of fitting weights after the optimizing the set of time series data record weights at least one time; and

storing, by the computing system, the optimized time series data record weights and the optimized fitting weights for use in monitoring for anomalies.

2. The non-transitory computer-readable medium of claim 1, wherein the actions further comprise determining an anomaly threshold value.

3. The non-transitory computer-readable medium of claim 1, wherein the plurality of time series data records include telemetry information from one or more autonomous vehicles.

4. The non-transitory computer-readable medium of claim 3, wherein the one or more autonomous vehicles includes at least one unmanned aerial vehicle (UAV).

5. The non-transitory computer-readable medium of claim 4, wherein the UAV includes at least one horizontal propulsion unit and at least one vertical propulsion unit.

6. The non-transitory computer-readable medium of claim 4, wherein the telemetry information includes information from at least two of a takeoff portion of a trip, a cruise portion of the trip, and a landing portion of the trip.

7. The non-transitory computer-readable medium of claim 4, wherein the time series data records include data that represents at least one of a motor speed, a control surface servo position, a linear velocity, an orientation, and an angular velocity.

8. The non-transitory computer-readable medium of claim 3, wherein the actions further comprise:

receiving a new time series data record from an autonomous vehicle; and

processing the new time series data record with the machine learning model to detect anomalies.

9. The non-transitory computer-readable medium of claim 8, wherein the actions further comprise, in response to detecting an anomaly:

determining an action to be taken to address the anomaly; and

transmitting a command to the autonomous vehicle to cause the autonomous vehicle to perform the action to address the anomaly.

10. The non-transitory computer-readable medium of claim 9, wherein the action to address the anomaly is at least one of rescheduling a future trip, navigating to an emergency repair location, immediately performing a landing procedure, and accepting remote control by a human operator.

11. A computer-implemented method of detecting and addressing anomalies in autonomous vehicle telemetry data, the method comprising:

initializing, by a computing system, a set of fitting weights for a machine learning model, wherein the fitting weights are used by the machine learning model to determine anomaly scores for new time series data records;

initializing, by the computing system, a set of time series data record weights associated with a training data set, wherein each time series data record weight is associated with a time series data record of a plurality of time series data records in the training data set, and wherein the time series data record weights are usable to identify one or more anomalous time series data records of the training data set to be ignored during optimization of the set of fitting weights;

training, by the computing system, the machine learning model by alternating at least two times between using the set of time series data record weights while optimizing the set of fitting weights based on the training data set, and using the set of fitting weights while optimizing the set of time series data record weights, wherein using the set of time series data record weights while optimizing the set of fitting weights includes ignoring at least one of the plurality of time series data records in the training data set based on the time series data record weights; and

storing, by the computing system, the optimized time series data record weights and the optimized fitting weights for use in monitoring for anomalies.

~~11~~12. ~~A~~ The method ~~for detecting anomalies in time series data records~~of claim 11, ~~the method~~further comprising:

receiving, by ~~a~~ the computing ~~device~~system, a new time series data record from an autonomous vehicle~~a monitored system~~;

processing, by the computing ~~device~~system, the new time series data record ~~using a~~with the machine learning model to generate an anomaly score~~, wherein the machine learning model was trained on a plurality of previous time series data records~~; and

~~comparing, by the computing device, the anomaly score to an anomaly threshold value; and~~

in response to determining that the anomaly score is greater than ~~the~~ an anomaly threshold value:

determining, by the computing ~~device~~system, an action to be taken to address the anomaly; and

transmitting, by the computing ~~device~~system, a command to the autonomous vehicle~~monitored system~~ to cause the autonomous vehicle~~monitored system~~ to perform the action to address the anomaly.

~~12. The method of claim 11, wherein the monitored system is an autonomous vehicle.~~

13. The method of claim 12, wherein the autonomous vehicle is an unmanned aerial vehicle (UAV).

14. The method of claim 13, wherein the UAV includes at least one horizontal propulsion unit and at least one vertical propulsion unit.

15. The method of claim 13, wherein the time series data record includes telemetry information from at least two of a takeoff portion of a trip, a cruise portion of the trip, and a landing portion of the trip.

16. The method of claim 13, wherein the time series data record includes data representing at least one of a motor speed, a control surface servo position, a linear velocity, an orientation, and an angular velocity.

17. The method of claim 13, wherein the action is at least one of rescheduling a future trip, navigating to an emergency repair location, and immediately performing a landing procedure.

~~18. The method of claim 11, further comprising training the machine learning model by performing actions including:~~

~~collecting a plurality of time series data records;~~

~~initializing the machine learning model to have a set of fitting weights and a set of time series data record weights;~~

~~optimizing the set of fitting weights while holding the set of time series data record weights constant; and~~

~~optimizing the set of time series data record weights while holding the set of fitting weights constant.~~

~~19. The method of claim 18, wherein training the machine learning model further includes determining the anomaly threshold value using the plurality of time series data records.~~

~~20. A system, comprising at least one computing device that includes:~~

~~at least one processor; and~~

~~a non-transitory computer-readable medium having logic stored thereon that, in response to execution by the at least one processor, causes the system to perform actions comprising:~~

~~receiving a time series data record from a monitored system;~~

~~processing the time series data record using a machine learning model to generate an anomaly score, wherein the machine learning model was trained on a plurality of previous time series data records;~~

~~comparing the anomaly score to an anomaly threshold value; and~~

~~in response to determining that the anomaly score is greater than the anomaly threshold value:~~

~~determining an action to be taken to address the anomaly; and~~

~~transmitting a command to the monitored system to cause the monitored system to perform the action to address the anomaly.~~

18. A system, comprising:

a computing system, the computing system having at least one computing device that includes at least one processor and a non-transitory computer-readable medium having logic stored thereon that, in response to execution by the at least one processor, causes the computing system to perform actions comprising:

initializing, by the computing system, a set of fitting weights for a machine learning model, wherein the fitting weights are used by the machine learning model to determine anomaly scores for new time series data records;

initializing, by the computing system, a set of time series data record weights associated with a training data set, wherein each time series data record weight is associated with a time series data record of a plurality of time series data records in the training data set, and wherein the time series data record weights are usable to identify one or more anomalous time series data records of the training data set to be ignored during optimization of the set of fitting weights;

training, by the computing system, the machine learning model by alternating at least two times between using the set of time series data record weights while optimizing the set of fitting weights based on the training data set, and using the set of fitting weights while optimizing the set of time series data record weights, wherein using the set of time series data record weights while optimizing the set of fitting weights includes ignoring at least one of the plurality of time series data records in the training data set based on the time series data record weights; and

storing, by the computing system, the optimized time series data record weights and the optimized fitting weights for use in monitoring for anomalies.

19. The system of Claim 18, further comprising an autonomous vehicle communicatively coupled to the computing system;

wherein the actions further comprise:

receiving, by the computing system, a new time series data record from the autonomous vehicle;

processing, by the computing system, the new time series data record with the machine learning model to generate an anomaly score; and

in response to determining that the anomaly score is greater than an anomaly threshold value:

determining, by the computing system, an action to be taken to address the anomaly; and

transmitting, by the computing system, a command to the autonomous vehicle that identifies the action to be taken; and

wherein the autonomous vehicle is configured to:

receive the command from the computing system; and

autonomously perform the action identified by the command.

20. The system of claim 19, wherein the autonomous vehicle is an unmanned aerial vehicle (UAV), and wherein autonomously performing the action identified by the command includes at least one of navigating to an emergency repair location or immediately performing a landing procedure.