US 20250256741A1

(19) **United States**

(12) **Patent Application Publication** (10) **Pub. No.: US 2025/0256741 A1**

UCAR et al. (43) **Pub. Date: Aug. 14, 2025**

(54) **COMPENSATE FOR PERFORMANCE DEGRADATION THROUGH VEHICULAR KNOWLEDGE NETWORKING**

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(21) Appl. No.: **18/436,781**

(22) Filed: **Feb. 8, 2024**

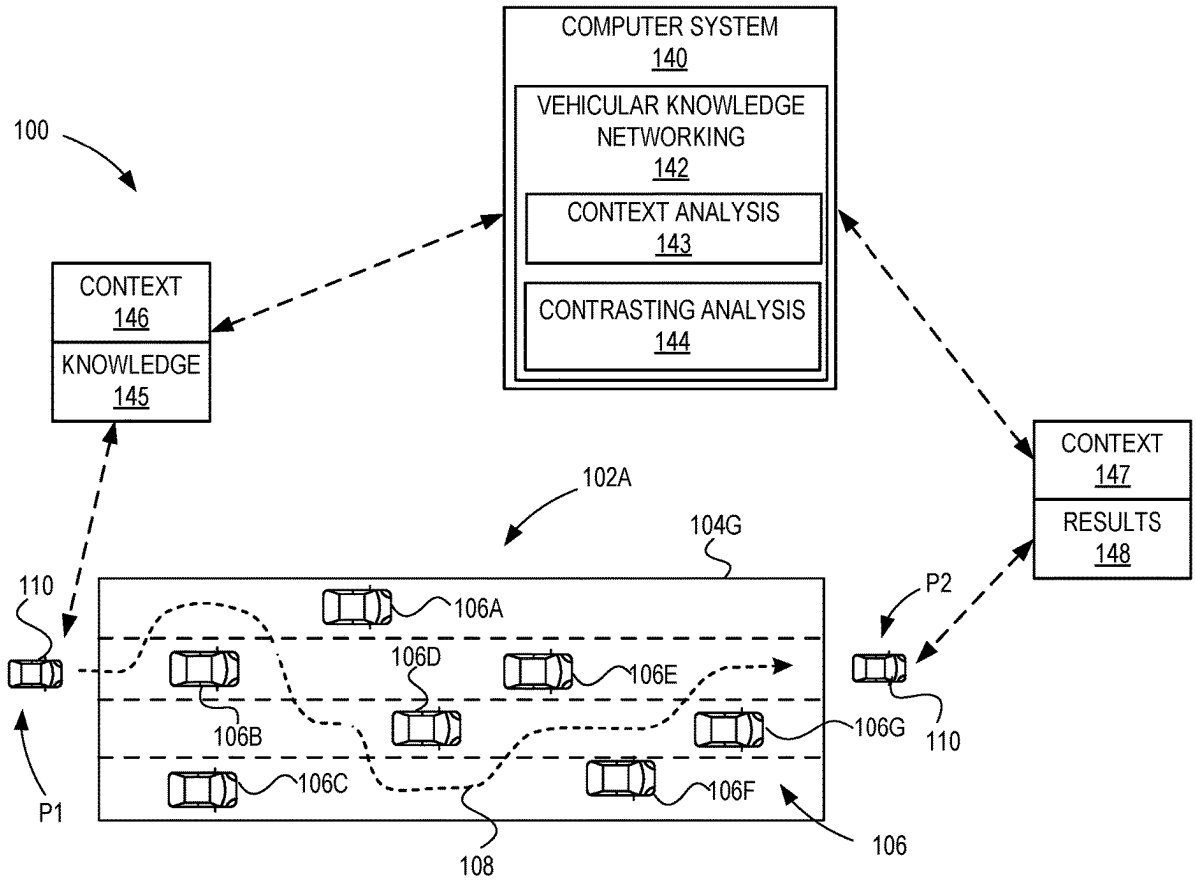
Publication Classification

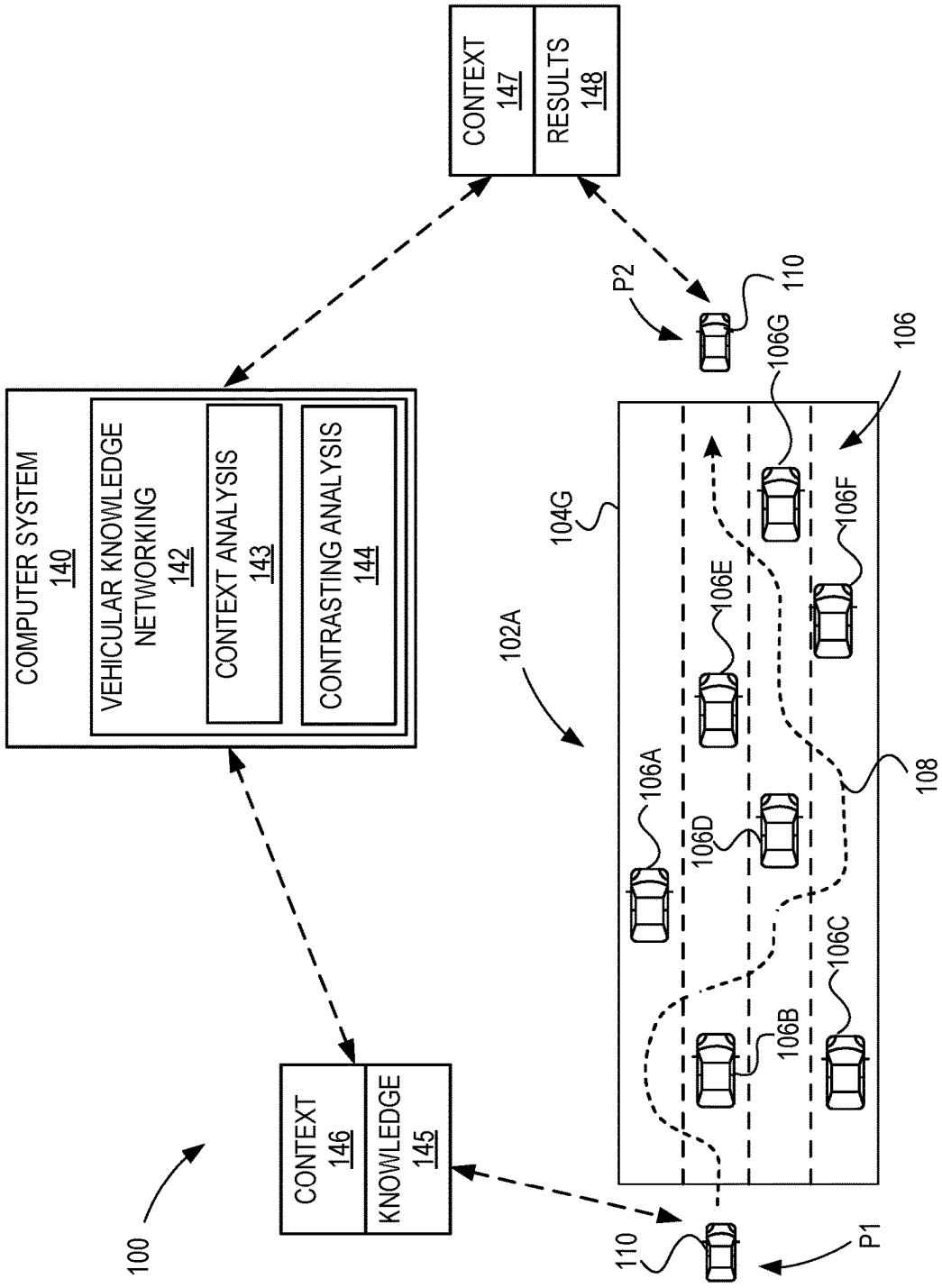
(51) **Int. Cl.**
B60W 60/00 (2020.01)

(52) **U.S. Cl.**
CPC ... ***B60W 60/00272*** (2020.02); *B60W 2554/40* (2020.02); *B60W 2556/45* (2020.02)

(57) **ABSTRACT**

Systems and methods are provided for compensating for performance degradation on an edge of the vehicular knowledge network. An example includes detecting a performance result of first guidance performed by a first vehicle in a first driving environment that differs from an expected result associated with the first guidance associated with a second driving environment that corresponds to the first driving environment, identifying behavior executed by the first vehicle associated with the detected performance result based on a comparison between the first driving environment to the second driving environment, and, based on detecting that a second vehicle is executing the identified behavior, generate second guidance to mitigate the identified behavior being executed by the second vehicle.

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RESULTS 148
COMPUTER SYSTEM 140
VEHICULAR KNOWLEDGE NETWORKING 142
CONTEXT ANALYSIS 143
CONTRASTING ANALYSIS 144
CONTEXT 146
KNOWLEDGE 145
100
102A
104G
106
106A
106B
106C
106D
106E
106F
106G
108
110
110
P1
P2

FIG. 1A

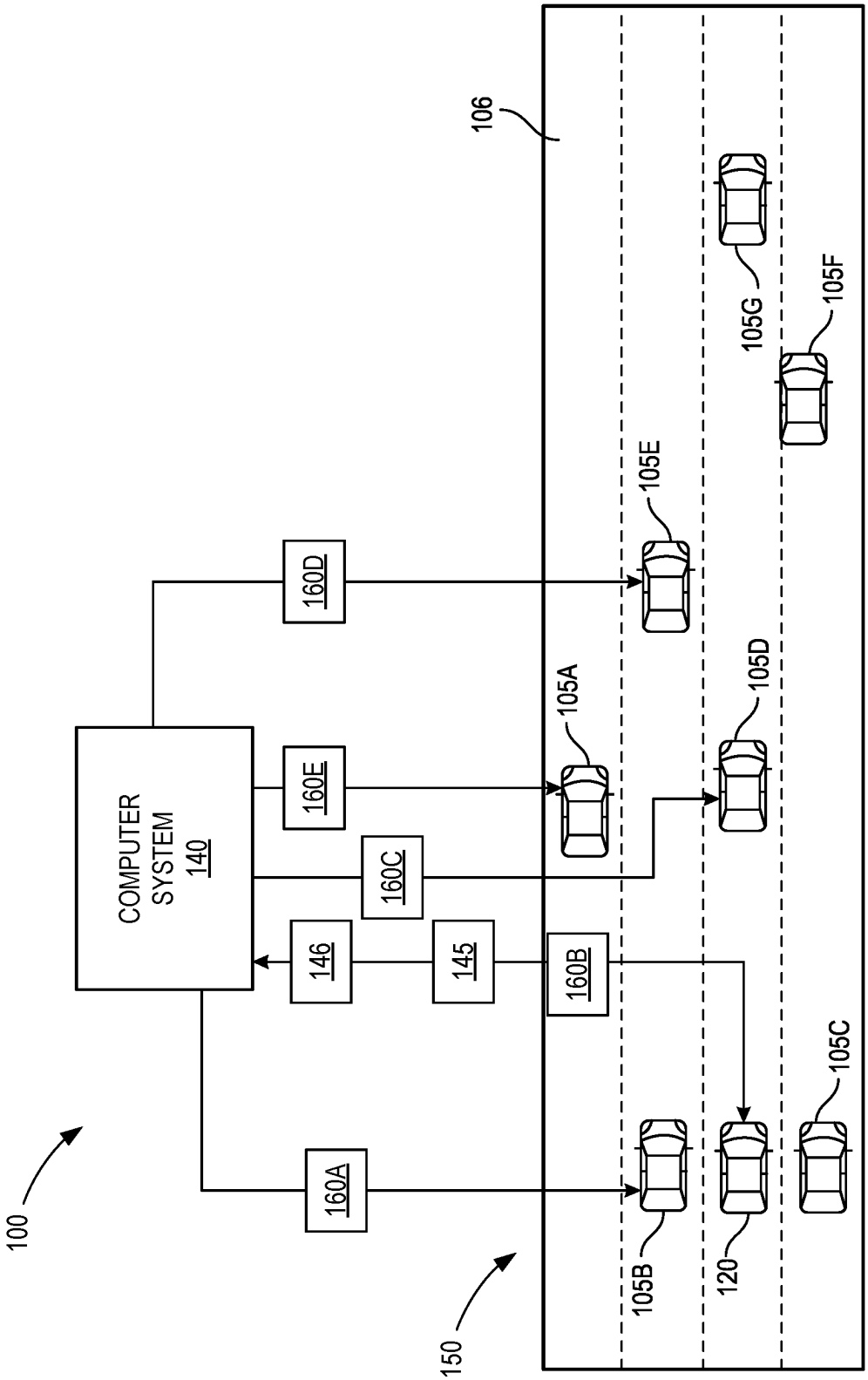
100
150
106
COMPUTER SYSTEM 140
160A
160B
160C
160D
160E
145
146
105A
105B
105C
105D
105E
105F
105G
120

FIG. 1B

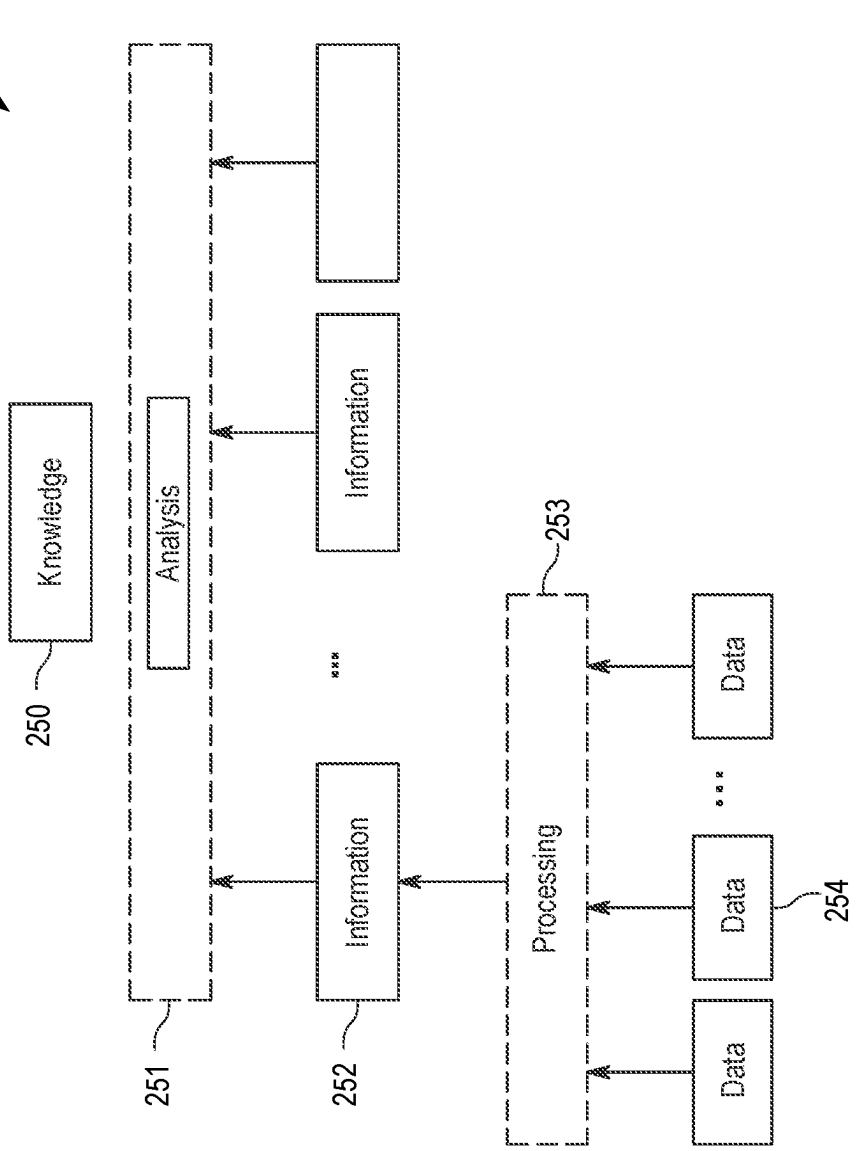
200
Knowledge
250
Analysis
Information
Information
Processing
253
Data
Data
Data
254
251
252

FIG. 2

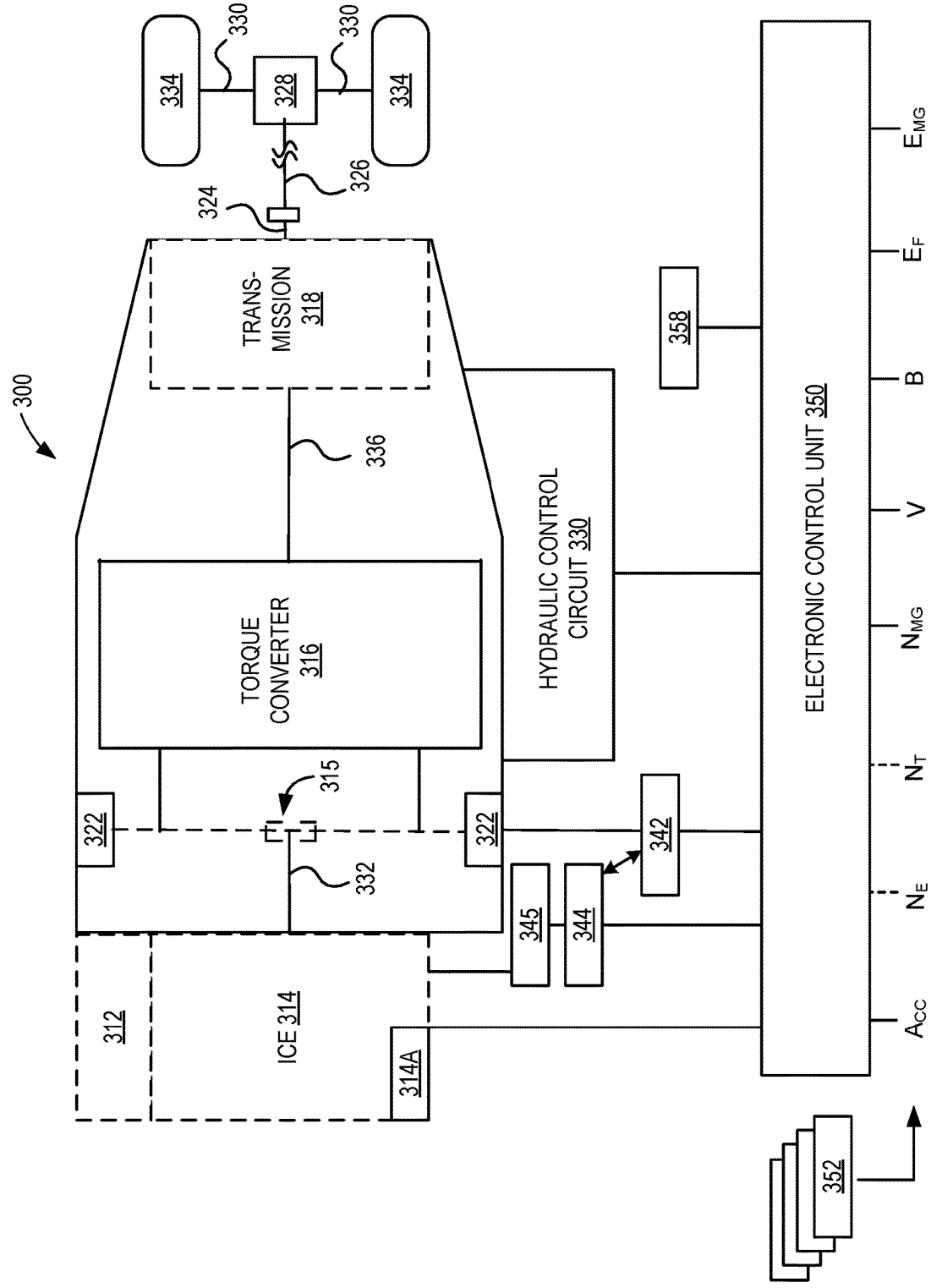
300
334
330
328
330
334
326
324
TRANS-
MISSION
318
336
TORQUE
CONVERTER
316
315
322
322
332
312
ICE 314
314A
HYDRAULIC CONTROL
CIRCUIT 330
358
345
344
342
ELECTRONIC CONTROL UNIT 350
E_{MG}
E_F
B
V
N_{MG}
N_T
N_E
A_{CC}
352

FIG. 3

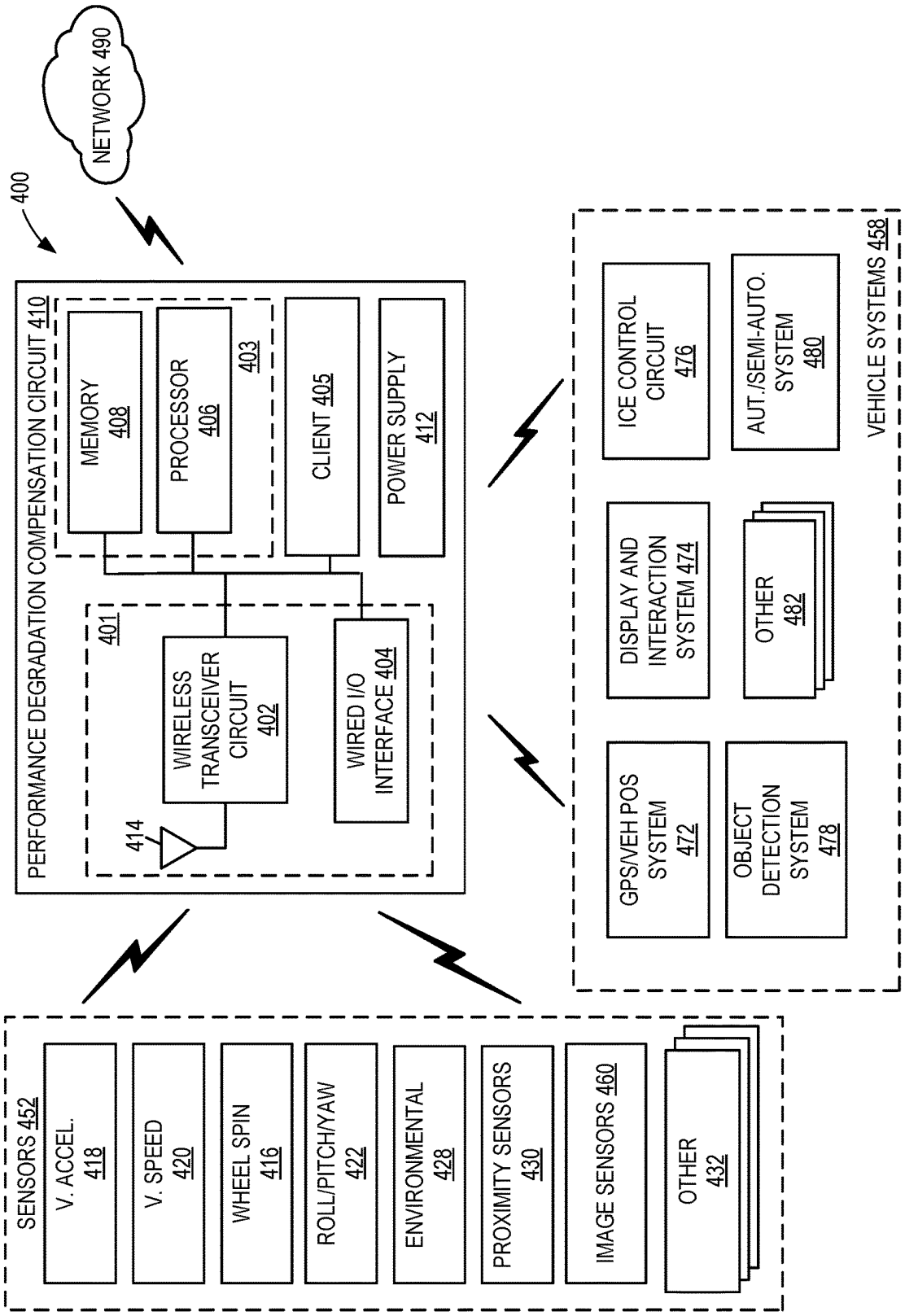
400
NETWORK 490
PERFORMANCE DEGRADATION COMPENSATION CIRCUIT 410
MEMORY 408
PROCESSOR 406
403
CLIENT 405
POWER SUPPLY 412
401
WIRELESS TRANSCEIVER CIRCUIT 402
WIRED I/O INTERFACE 404
414
SENSORS 452
V. ACCEL. 418
V. SPEED 420
WHEEL SPIN 416
ROLL/PITCH/YAW 422
ENVIRONMENTAL 428
PROXIMITY SENSORS 430
IMAGE SENSORS 460
OTHER 432
VEHICLE SYSTEMS 458
ICE CONTROL CIRCUIT 476
AUT./SEMI-AUTO. SYSTEM 480
DISPLAY AND INTERACTION SYSTEM 474
OTHER 482
GPS/VEH POS SYSTEM 472
OBJECT DETECTION SYSTEM 478

FIG. 4

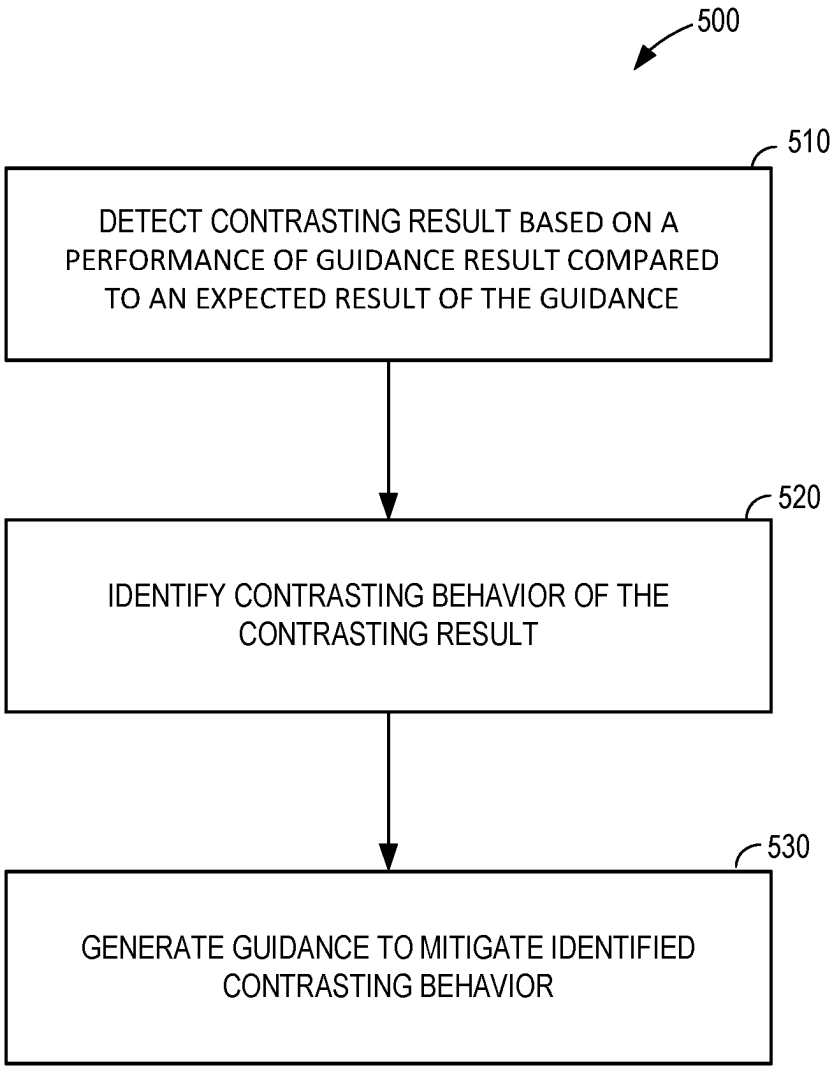
500
510
DETECT CONTRASTING RESULT BASED ON A PERFORMANCE OF GUIDANCE RESULT COMPARED TO AN EXPECTED RESULT OF THE GUIDANCE
520
IDENTIFY CONTRASTING BEHAVIOR OF THE CONTRASTING RESULT
530
GENERATE GUIDANCE TO MITIGATE IDENTIFIED CONTRASTING BEHAVIOR

FIG. 5

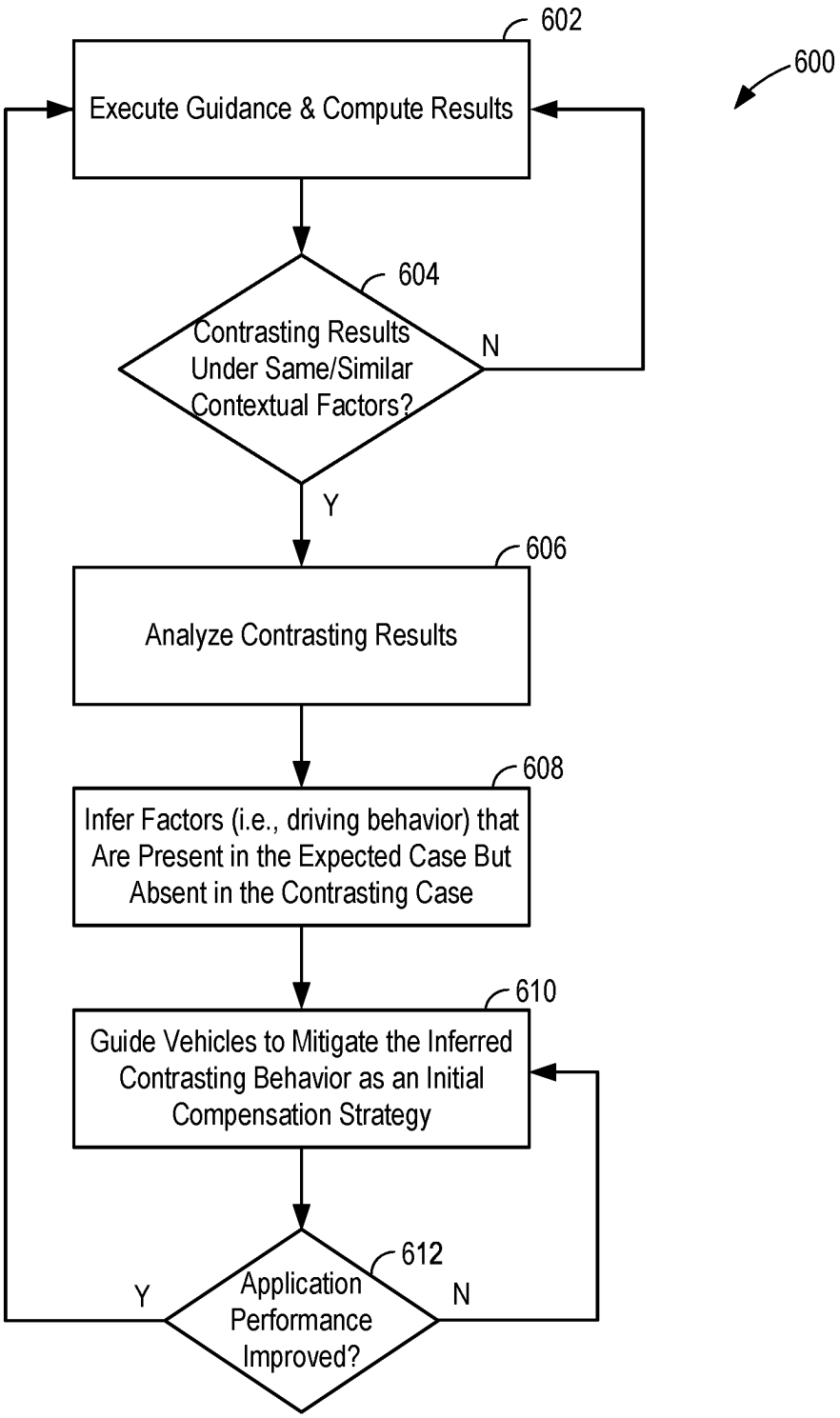
600
602
Execute Guidance & Compute Results
604
Contrasting Results Under Same/Similar Contextual Factors?
N
Y
606
Analyze Contrasting Results
608
Infer Factors (i.e., driving behavior) that Are Present in the Expected Case But Absent in the Contrasting Case
610
Guide Vehicles to Mitigate the Inferred Contrasting Behavior as an Initial Compensation Strategy
612
Application Performance Improved?
Y
N

FIG. 6

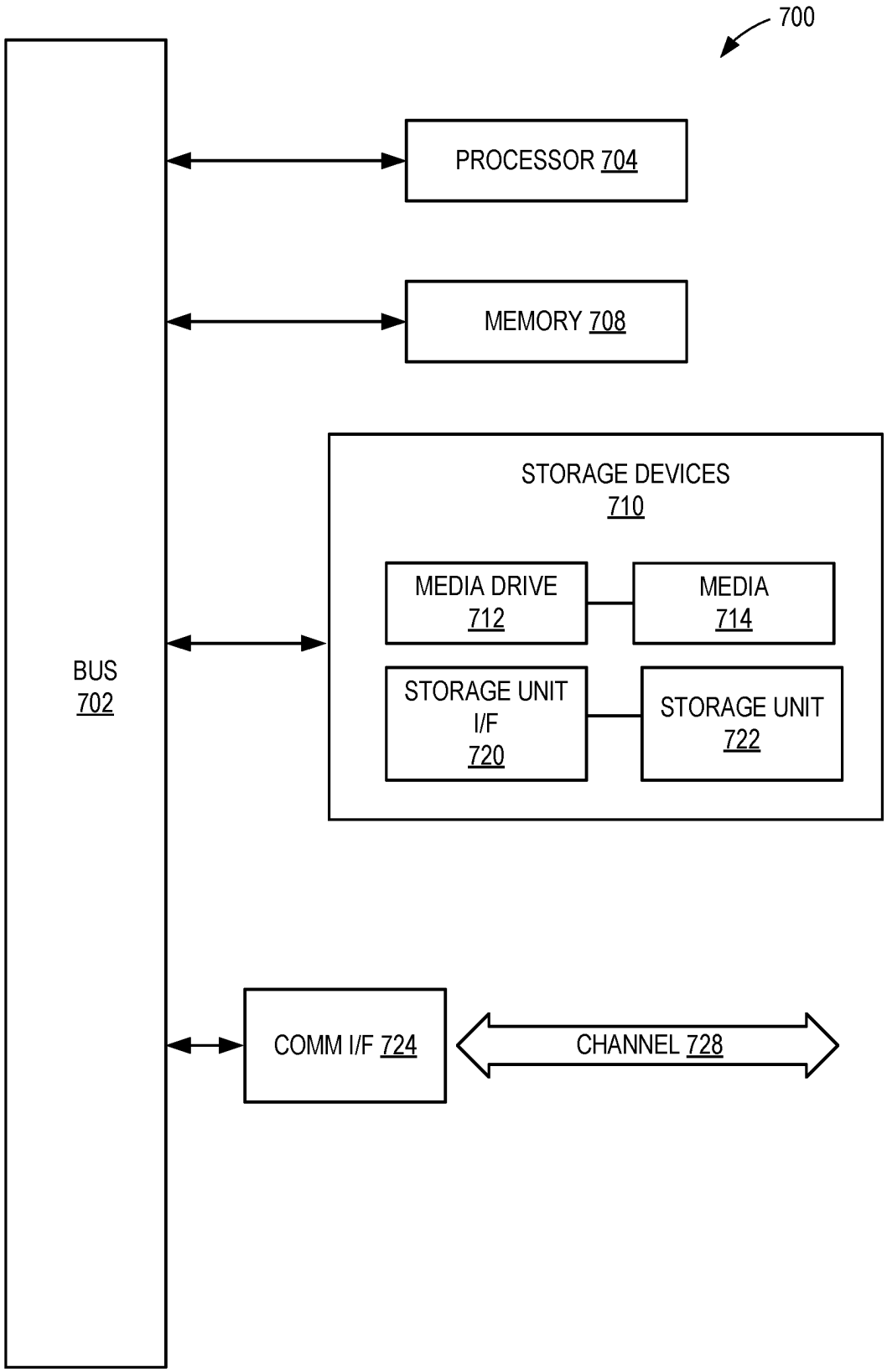
700
PROCESSOR 704
MEMORY 708
STORAGE DEVICES
710
MEDIA DRIVE
712
MEDIA
714
STORAGE UNIT
I/F
720
STORAGE UNIT
722
BUS
702
COMM I/F 724
CHANNEL 728

FIG. 7

COMPENSATE FOR PERFORMANCE DEGRADATION THROUGH VEHICULAR KNOWLEDGE NETWORKING

REFERENCE TO RELATED APPLICATIONS

[0001] The present application is related to U.S. patent application Ser. No. 16/365,092, filed Mar. 26, 2019, and titled "VEHICULAR KNOWLEDGE DISTRIBUTION SYSTEM;" U.S. patent application Ser. No. 16/735,612, filed Jan. 6, 2020, and titled "VEHICULAR MICRO CLOUD HUBS;" U.S. patent application Ser. No. 18/173,524, filed Feb. 23, 2023, and titled "SYSTEMS AND METHODS TO IMPROVE KNOWLEDGE CYCLES IN VEHICULAR KNOWLEDGE NETWORKING;" U.S. patent application Ser. No. 18/300,367, filed Apr. 13, 2023, and titled "SYSTEMS AND METHODS FOR CONTEXT BASED KNOWLEDGE FORWARDING IN VEHICULAR KNOWLEDGE NETWORKING," which are incorporated herein by reference in entirety.

TECHNICAL FIELD

[0002] The present disclosure relates generally to systems and methods for vehicular knowledge networking, and, more particularly, some embodiments relate to compensation for performance degradation through vehicular knowledge networking.

DESCRIPTION OF RELATED ART

[0003] Technological advancements in the realm of communication networking have led to an emergence of "vehicular networking" (or connected vehicles), where direct connections between vehicles and other points (e.g., infrastructure, network, cloud, etc.) are enabled. With the various types of vehicle communication capabilities that have become available, vehicular networking may be further leveraged to support the concept of sharing "knowledge" in a manner that improves the operation of vehicles.

[0004] Occasionally, driving scenarios exist where driver's do not know how to behave. For example, a driver may not understand how to safely perform a merge maneuver with a plurality of vehicles all traveling uniformly in the same lane. A driver may also not know how to proceed through an atypical intersection. Not knowing how to behave in these scenarios can result in accidents. In instances such as these, equipping vehicles with the capability to analyze, store, and share knowledge (e.g., knowledge of how to maneuver safely in certain situations) is promising and can improve vehicle safety and overall performance.

BRIEF SUMMARY OF THE DISCLOSURE

[0005] According to various embodiments of the disclosed technology, systems and methods for managing vehicles to mitigate risk to the vehicles due to anomalous driving behavior are provided.

[0006] In accordance with some embodiments, a method is provided. The method comprises detecting a performance result of first guidance performed by a first vehicle in a first driving environment that differs from an expected result associated with the first guidance associated with a second driving environment that corresponds to the first driving environment, identifying behavior executed by the first vehicle associated with the detected performance result based on a comparison between the first driving environment to the second driving environment, and, based on detecting that a second vehicle is executing the identified behavior, generate second guidance to mitigate the identified behavior being executed by the second vehicle.

[0007] In another aspect, an apparatus of a vehicular knowledge network is provided that comprises a memory storing instructions and a processor communicably coupled to the memory storing. The processor is configured to execute the instructions to obtain a performance result of first guidance performed by a first vehicle in a first driving environment, wherein the first guidance is associated with a second driving environment that corresponds to the first driving environment. The processor is also configured to execute the instructions to determine that the performance result differs from an expected result associated with the first driving environment; based on the determination, infer behavior of the first vehicle based on a comparison between the first driving environment to the second driving environment; and, based on detecting that a second vehicle is executing the identified behavior, generate second guidance configured to mitigate the inferred behavior being executed by the second vehicle.

[0008] In another aspect, a system is provided that comprises a memory storing instructions and a processor communicably coupled to the memory storing. The processor is configured to execute the instructions to identify driving behavior of a first vehicle in a first driving environment that deviates from expected driving behavior based on the first vehicle executing guidance, and generate compensation guidance configured to mitigate the identified driving behavior being performed by a second vehicle.

[0009] Other features and aspects of the disclosed technology will become apparent from the following detailed description, taken in conjunction with the accompanying drawings, which illustrate, by way of example, the features in accordance with embodiments of the disclosed technology. The summary is not intended to limit the scope of any inventions described herein, which are defined solely by the claims attached hereto.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] The present disclosure, in accordance with one or more various embodiments, is described in detail with reference to the following figures. The figures are provided for purposes of illustration only and merely depict typical or example embodiments.

[0011] FIGS. **1**A and **1**B depict example illustrations of vehicle environments implementing a vehicular knowledge networking system in accordance with embodiments disclosed herein.

[0012] FIG. **2** depicts a conceptual diagram for a hierarchal architecture for data, information, and knowledge used in a vehicular knowledge network, for example the vehicular knowledge network of FIGS. **1**A and **1**B in accordance with embodiments disclosed herein.

[0013] FIG. **3** is a schematic representation of an example hybrid vehicle with which embodiments of the systems and methods disclosed herein may be implemented.

[0014] FIG. **4** illustrates an example architecture for performance compensation in vehicular knowledge networking in accordance with one embodiment of the systems and methods described herein.

[0015] FIG. **5** is a flow chart illustrating example operations for compensation of performance degradation in vehicular knowledge networking in accordance with embodiments disclosed herein.

[0016] FIG. **6** is flow chart illustrating an example process for performance degradation compensation in vehicular knowledge networking in accordance with embodiments disclosed herein.

[0017] FIG. **7** is an example computing component that may be used to implement various features of embodiments described in the present disclosure.

[0018] The figures are not exhaustive and do not limit the present disclosure to the precise form disclosed.

DETAILED DESCRIPTION

[0019] On occasion, in certain complicated driving environments, a driver may behave in a manner that differs from other drivers. In other words, a driver's behavior may contrast from other drivers. A driver's behavior can refer generally to actions, reactions, or operations, which may be performed or undertaken by a driver while operating a vehicle. At certain times while operating a vehicle, traffic conditions, environmental conditions, or the vehicle's condition and/or operating state may cause or result in a driver to take actions, reaction, or driving decision, which diverge from other drivers upon encountering such a condition. For example, when a driver enters into a roundabout, or when a driver is attempting to merge into a lane with a platoon of vehicles (i.e., a series of vehicles traveling at roughly the same speed in the same lane at roughly the same intervals), the driver may not know the right-of-way rules associated with the roadway or the traffic pattern. Another such example is when a driver misses their intended exit, and as a result may be confused as to whether they should refrain from performing any risky driving maneuvers (e.g., keep going and eventually loop back around) which then causes them to have to reroute. However, in this scenario, some drivers decide to engage in contrasting behavior in attempt to reach the correct exit, such as perform abrupt lane changes or slam on the brakes on the shoulder of the road, hoping they can still make the turn. In order to address the aforementioned and similar issues, equipping vehicles with capabilities to infer and share guidance in instances in these complicated driving environments (referred to herein as risky zone) may mitigate collision risk in these zones, thereby preventing vehicular damage, bodily injury and/or fatality, and significantly improving overall driver safety.

[0020] Some conventional methods to improve vehicle safety typically include providing feedback as the driver engages in an unsafe driving maneuver. For example, a current driver/vehicle safety system may produce an audible notification to warn the driver that they are attempting to move into a lane that is already occupied by another vehicle. Particularly, a current driver/vehicle safety system may beep if a driver attempts to change lanes and does not see another vehicle in his/her blind spot, in order to notify the driver of the vehicle in his/her blind spot. Although such safety alerts can be helpful, current driver/vehicle safety systems are often restricted to functioning while the driver is in the middle of a dangerous maneuver (e.g., providing little to no reaction time) which increases the risk of a catastrophic collision. In other words, these conventional driver/vehicle safety systems do not proactively provide guidance and/or knowledge that the driver can utilize while they are still approaching a risky zone. Although reactive feedback methods offer some level of prevention, a predictive system and method could prevent the drivers from engaging in the unsafe driving maneuver altogether.

[0021] In contrast to the aforementioned conventional systems, the disclosed system distinctly leverages communicating "knowledge" between vehicles (also referred to herein a vehicular knowledge networking) in a manner that can guide a driver through a complicated driving environment. In some examples, this "knowledge" can be used to proactively warn drivers in risky zones (e.g., risky and/or confusing driving environments). For instance, the disclosed system employs vehicular networking capabilities, such as vehicle-to-vehicle (V2) communication, to create and distribute contextual knowledge of risky zones. This knowledge can be received by a vehicle (e.g., a driver approaching said risky zone) early, allowing the driver to be preemptively prepared before entering the complicated driving environment and then safely maneuver once driving inside of the environment. This guidance may be referred to as knowledge-based guidance. Alternatively, with using conventional driver/vehicle safety systems, the driver would not be warned until they are already in the complicated driving environment, confused, and performing contrasting maneuvers that could cause a dangerous crash. Because it is so crucial to stay alert and aware of complicated driving environments, like risky zones, while driving, the disclosed embodiments utilize vehicular knowledge networking to implement a more effective safety system that equips vehicles to provide a priori guidance (e.g., prior to entering the risky zone) in a manner that thwarts driver confusion and enables the driver to be ready for maneuvering safely before reaching the risky zone. Restated, the vehicular knowledge network system and methods proposed herein, leverage knowledge to assist drivers in various driver/vehicle safety applications, such as risk reasoning and vehicular maneuvering in a manner that is preemptive and provides improvements over the reactionary (i.e., systems based on the driver engaging, or attempting to engage in a driving maneuver) limitations of conventional driver/vehicle safety systems.

[0022] Furthermore, the disclosed embodiments include a context-based knowledge forwarding process which ties a contextual meaning to knowledge, with the objective of ensuring that knowledge, and corresponding guidance, is received within the proper context and ultimately more accurate. As described herein, context is related to circumstances, descriptors, and situational characteristics for an event and/or location (e.g., driving environment) in terms that allow the environment to be understood and assessed by a computation system. With respect to vehicular knowledge networking, a "context" can be formed from several characteristics that describe aspects of the driving environment, such as road geometry, traffic flow, and the like, which are linked to a time when the knowledge was initially created. For example, knowledge of a complicated driving environment may be created using the data obtained from vehicles that were experiencing clear weather conditions while traveling a given location. This knowledge can be utilized by trained machine learning models to generate knowledge-based guidance, which can be provided to vehicles traveling in this environment. However, it may be detrimental if an ego vehicle currently driving in that same location, but in rainy weather conditions, attempts to apply that knowledge (having a "clear weather" context) for its complicated driv-

ing environment analysis. If knowledge is utilized in the wrong context, even when it is the "correct" knowledge (e.g., knowledge for the right location and/or event), the knowledge's accuracy may be undermined in a manner that negatively affects the vehicle's functions, for instance, leading to the vehicle making contrasting decisions relative to the knowledge, which impacts the overall driver/vehicle safety. In other words, the accuracy and usefulness of knowledge can be weakened when the knowledge is retrieved in a context that is dissimilar to the context in which it was created.

[0023] Thus, context-based knowledge forwarding, as disclosed herein, ensures that the proper knowledge is also retrieved in the proper context. For example, in accordance with context-based knowledge forwarding, a vehicle that queries knowledge within the context of traveling in rainy weather conditions, particularly receives knowledge that was created in a similar rainy weather context. The disclosed embodiments include a distinct process that assigns various contextual features to knowledge during a knowledge cycle, particularly while the knowledge is created (e.g., forming a contextual frame for knowledge), and later leverages these contextual features when the knowledge is forwarded to be utilized by entities in the vehicular knowledge network. A knowledge cycle, as described herein, includes several interrelated stages that involve dissemination and utilization of knowledge, including: knowledge creation; knowledge storing; knowledge networking; and knowledge refining (e.g., knowledge transfer and knowledge composition). The aforementioned knowledge cycle, the entities involved in the communication (e.g., vehicles, infrastructure, etc.), the vehicular network (e.g., vehicle-to-vehicle networking, vehicle-to-cloud networking, etc.), data (e.g., knowledge), and functionality related to creating and using knowledge can be referred to collectively as "vehicular knowledge networking." Consequently, by making certain that knowledge is used in the correct context, the disclosed embodiments ensure that knowledge is increasingly accurate and beneficial within the vehicular knowledge network, thereby realizing improved vehicle/driver safety features.

[0024] As referred to herein, "knowledge" is conceptually a state of understanding that is obtained through experience and analysis of collected information, such as raw data. A function of the vehicular knowledge network, as disclosed herein, is the capability to transform data, such as raw data collected from vehicle sensors, into searchable knowledge, and subsequently to create and distribute this knowledge with various life cycles and relevance. Referring now to FIG. **2**, a conceptual diagram depicts a hierarchy among data **254**, information **252**, and knowledge **250**. As seen in FIG. **2**, the hierarchy can include data **254** which is a piece of a recorded experience, such as vehicular speed mph, time t, position p that may be collected as raw data from the vehicle's sensors. In addition, the hierarchy can include information **252** which is pieces of data **254** that have been subjected to processing **253**. Thus, data **254** can be contextual "meaningful." For instance, continuing with the example, the aforementioned raw data **254** from the vehicle can be processed to ascertain meaningful information **252** about the vehicle, such as "the vehicle was moving at a speed mph at time t and at position p." Further, FIG. **2** illustrates that information **252** can be subjected to analysis **251** in order to derive knowledge **250**. It is knowledge **250** that is the most contextual-rich in comparison to data **254** and information **252**, which is as illustrated by knowledge **250** being at the top of the hierarchy. As alluded to above, knowledge **250** can be considered as a fact, a belief extracted by analyzing patterns in information **252**. For instance, knowledge **250** can be created through analysis **251** of multiple instances of information **252** and it is a fact or a belief that represents the hidden relationship among the information **252**. Again, continuing with the example, knowledge **250** can be inferred insight surrounding the vehicle, where knowledge **250** identifies that sequential conflicts happen the most in an area X (related to vehicle's location P), thus X is a risky zone. The creation of knowledge **250** may require computationally hungry algorithms and a set of information **252** and/or data **254** that are potentially from multiple sources (e.g., vehicles). In operation, the vehicular knowledge network depicted in FIG. **2** organizes vehicle sensor measurements into data **254**, information **252**, and knowledge **250**. Moreover, contextual data (also referred to herein as contextual features) for knowledge define a degree of similarity in data **254**, information **252** and knowledge **250**. For instance, types of data **254** that describe various situational conditions that the vehicle is traveling in at a location, such as road geometry, traffic flow/congestion, weather conditions, and the like, can be collected to form a contextual frame around that location, and ultimately a context for the knowledge **250** for that location. Restated, the disclosed embodiments use certain data **254** as contextual features that link a contextual relevance, namely a context, to the corresponding knowledge **250**. Further, the contextual features can be analyzed to determine whether knowledge **250** is in the right context (e.g., having similar contextual features) for a specific vehicle query.

[0025] One challenge in determining knowledge for the right context is that it practically infeasible to cover all scenarios for a set of contextual features. There will likely be some scenarios and/or conditions that have not yet been seen in the raw data. As a result, knowledge associated with one set of contextual features may be used by a model to provide guidance to a vehicle experiencing a substantially similar set of contextual, but which differ in some aspect with the one set of contextual features. In some corner cases, the divergence between sets of contextual features may translate performance of the applied guidance (referred to herein as "performance result") that differs from an expected performance result. This contrasting result can represent performance degradations in the knowledge, whereby a vehicle experiences an desired or unexpected departure in performance of the knowledge-based guidance due to unforeseen or unexpected changes in a driving environments.

[0026] For example, a battery electric vehicles (BEVs) may be provided knowledge-based guidance according to a first set of contextual features obtained from a first driving environment in which the BEV is traveling. The knowledge-based guidance may be associated with a second set of contextual features indicative of a second driving environment, which may be substantially similar or the same as (e.g. corresponding to) the first set of contextual features. The knowledge-based guidance may be associated with a performance result that is expected after executing the guidance (an "expected performance result), which in this example may be an estimate of available driving range after executing the guidance. However, in this case, after executing the knowledge-based guidance the BEV determines a perfor-

mance result that differs from the expected result (e.g., a lower than expected estimate of available driving range). This discrepancy between the actual performance result and the expected performance result may be an example of a contrasting result. As another example, a vehicle may travel to a destination according to a mapped knowledge-based guidance, but with a contrasting arrival times (e.g., actual arrival time differs from expected arrival time). These differences, which can be considered contrasting results, may represent corner cases in which performance deviates from expected results for an unknown or unforeseen reason.

[0027] Application developers can collect information and sensor measurement about corner cases and analyze these corner cases to refine knowledge and how the knowledge is translated to knowledge-based guidance. The refined knowledge can provide better guidance to a driver by compensating for the performance degradation. However, performance of guidance can depend on many varying, interacting, and complicated factors. For example, knowledge shared and the resulting guidance provided can be dependent on driving behavior of an ego vehicle, driving behavior of surrounding vehicles, interactions therebetween, traffic conditions, environmental conditions, the vehicles' condition and/or operating state, etc. Collecting large quantities of data related to these factors, transferring the data to model developers, analyzing the data (including performance results), and retrieving the refined application may not be practically feasible in certain cases. For example, it could take months or years to collect for an application developer to refine a model to properly compensate for each corner case, and during that time drivers may suffer by using a model that is unable to handle these corner cases. Furthermore, it may be not be feasible to generate knowledge of all corners cases that a vehicle may experience, by definition these corner cases are unforeseen situations or unknown scenarios that may not have been predictable to the model developer.

[0028] It may be advantageous to expediate compensating for performance degradation at the edge of a vehicular knowledge networking, while knowledge-based guidance models are refined by developers on the backend. Some approaches have been proposed that attempt to compensate for degradation in performance. For example, movement patterns (e.g., driving habits) have been analyzed using digital twin simulations to identify potential conflicts. In this case, drivers are coached to correct these habits and improve driving performance. In another example, metadata has been linked to anomaly detection, which can be used to dynamically update detection rules to improve detection accuracy. However, these approaches generally aim to retrieve and deliver the right knowledge with the right context in a timely manner. Any compensation for performance degradation, in the conventional systems, is addressed by dynamically updating the logic behind the guidance. Yet, as outlined above, performance can depend on many factors, and updating the logic behind the performance (e.g., updating the digital twin simulation and/or updating detection rules) may not be feasible.

[0029] Embodiments herein are provided that can compensate for performance degradation on the edge of the vehicular knowledge network, without requiring refining the knowledge and updating the guidance model. Embodiments disclosed herein leverage contrasting results analysis and guiding vehicles in a manner to improve performance. For example, embodiments disclosed herein can detect a contrasting result of knowledge-based guidance performed by a vehicle. In examples, a vehicle may be traveling in a first environment and may execute guidance that is based on knowledge corresponding to a second environment that is substantially similar or identical as (e.g., corresponding to) the first environment. A performance result of the guidance can be compared to an expected result associated with the knowledge (and thusly the knowledge-based guidance) to determine if the real-world performance result differs from the expected performance result. If the results differ, the real-world performance results are identified as a contrasting result. Said another way, the measured performance results of the guidance contrast relative to the expected results. In some embodiments, differing results may be determined where the difference therebetween is outside a defined deviation (e.g., 5%, 10%, etc. difference between real-world and expected results).

[0030] Based on (e.g., responsive to) identifying contrasting results, contrasting behavior analysis can be performed to identify contrasting driving behavior of the first vehicle. Contrasting behavior analysis may comprise inferring factors, such as driving behaviors and/or contextual features, differ between the first and second driving environments. The inferred contextual factors, which may be indicative of contrasting driving behavior, can be used to construct a compensation guidance plan (sometimes referred to as second guidance) that can be provided to vehicles as an initial compensation strategy to improve performance (e.g., bring real-world measured performance results in line with expected results) of the knowledge-based guidance by mitigating the contrasting behavior identified in other vehicles. The compensation guidance plan may be associated with the knowledge by tagging, such that when the knowledge is retrieved and used to provide knowledge-based guidance, the compensation guidance can be added to the knowledge-based guidance in real-time. Information of the first driving environment, including the identified contrasting behavior, can be uploaded to a centralized server for use by a developer to analyze and refine the guidance model.

[0031] In an example, the compensation guidance can be implemented by identifying a subsequently performed contrasting behavior (e.g., contrasting behavior performed after constructing the compensation guidance) by a vehicle and then guiding the vehicle to mitigate this subsequently performed contrasting driving. For example, in the above BEV example, embodiments disclosed herein learn that aggressive driving (e.g., unnecessary acceleration and deceleration) is a cause of the contrasting results. Then, as an initial compensation, embodiment disclosed herein construct compensation guidance that guides vehicles with speed and lane change advice to avoid such aggressive driving.

[0032] While examples provided herein are described as detecting contrasting results of knowledge-based guidance, the scope of the embodiments is not intended to be limited to knowledge-based guidance only. Embodiments disclosed herein may be able to detect contrasting results from any guidance or model, not only knowledge-based guidance. For example, a navigation application may generate guidance in the form of map with an expected arrival time. A contrasting result may be detected in a case where a real-world arrival time differs from the expected arrival time.

[0033] It should be noted that the terms "optimize," "optimal" and the like as used herein can be used to mean making or achieving performance as effective or perfect as possible.

However, as one of ordinary skill in the art reading this document will recognize, perfection cannot always be achieved. Accordingly, these terms can also encompass making or achieving performance as good or effective as possible or practical under the given circumstances, or making or achieving performance better than that which can be achieved with other settings or parameters.

[0034] FIG. **1**A is a schematic diagram of an example environment **102** in which a vehicular knowledge network system **100** can be implemented. The example operating environment **102** includes a vehicle **110**, and one or more vehicles **104**A-**104**G traveling in a driving environment on a section of roadway **106**. The vehicles **104**A-**104**G may be traveling in any configuration or arrangement. The roadway **106** may feature any type of traffic signals, roadway patterns, roadway hazards etc. It should be understood that the operational environment **102** in FIG. **1**A is described for purposes of illustration and is not intended to be limiting, thus the described vehicular knowledge networking and performance degradation compensation capabilities can implement enhanced driver/vehicle guidance functions that are similarly applicable to various other types of potentially risky, confusing, or dangerous driving environments that are not shown (e.g., roundabouts, exits, and the like).

[0035] The embodiments disclosed herein may be implemented with any of a number of different vehicles and vehicle types. For example, embodiments disclosed herein may be used with automobiles, trucks, motorcycles, recreational vehicles and other like on-or off-road vehicles. In addition, the principals disclosed herein may also extend to other vehicle types as well. Although the example described with reference to FIG. **1**A is a type of semi-autonomous vehicle, the systems and methods described herein can be implemented in other types of vehicles including autonomous vehicles, vehicles with automatic controls (e.g., dynamic cruise control), or other vehicles. In some examples, the vehicle **110** may be implemented as vehicle **300** described in connection with FIG. **3**. The disclosed embodiments can be implemented in any type of vehicles including gasoline- or diesel-powered vehicles, fuel-cell vehicles, hybrid-electric vehicles (HEV), BEVs, or other vehicles.

[0036] Vehicle **110** can be a semi-autonomous vehicle, such as a vehicle having assisted driving capabilities, which also implements the vehicular knowledge networking and improved knowledge cycle functions, as disclosed herein. "Semi-autonomous operational mode" means that a portion of the navigation and/or maneuvering of the vehicle **110** along a travel route is performed by one or more computing systems, and a portion of the navigation and/or maneuvering of the vehicle **110** along a travel route is performed by a human driver. In examples disclosed herein, the navigation and/or maneuvering may be based on knowledge-based guidance. One example of a semi-autonomous operational mode is when an adaptive cruise control system is activated. In such case, the speed of a vehicle **110** can be automatically adjusted to maintain a safe distance from a vehicle ahead based on data received from on-board sensors, but the vehicle **110** is otherwise operated manually by a human driver. Upon receiving a driver input to alter the speed of the vehicle (e.g., by depressing the brake pedal to reduce the speed of the vehicle), the speed of the vehicle is reduced. Thus, with vehicle **110** operating as a semi-autonomous vehicle, a response can be partially automated. In an example, the controller communicates a newly generated (or updated) control to the vehicle **110** operating as a semi-autonomous vehicle. The vehicle **110** can automatically perform some of the desired adjustments (e.g., accelerating) with no human driver interaction. Alternatively, the vehicle **110** may notify a driver that driver input is necessary or desired in response to a new (or updated) safety control.

[0037] Alternatively, or in addition to the above-described modes, vehicle **110** can have one or more autonomous operational modes. As used herein, "autonomous vehicle" means a vehicle that is configured to operate in an autonomous operational mode. "Autonomous operational mode" means that one or more computing systems of the vehicle **110** are used to navigate and/or maneuver the vehicle along a travel route with a limited level of input from a human driver which varies with the operational mode. In examples disclosed herein, the autonomous operation may be based on knowledge-based guidance. As such, vehicle **110** can have a plurality of autonomous operational modes, where each mode correspondingly responds to a controller, with a varied level of automated response. In some embodiments, the vehicle **110** can have an unmonitored autonomous operational mode. "Unmonitored autonomous operational mode" means that one or more computing systems are used to maneuver the vehicle along a travel route fully autonomously, requiring no input or supervision required from a human driver. Thus, as an unmonitored autonomous vehicle **110**, responses can be highly, or fully, automated. For example, a controller can be configured to communicate controls so as to operate the vehicle **110** autonomously and safely. After the controller communicates a control to the vehicle **110** operating as an autonomous vehicle, the vehicle **110** can automatically perform the desired adjustments (e.g., accelerating or decelerating) with no human driver interaction. Accordingly, vehicle **110** can operate any of its components autonomously, such as an engine.

[0038] The plurality of vehicles depicted in the example environment **102** of FIG. **1**A includes the vehicle **110** and vehicles **104**A-**104**G. Vehicles **104**A-**104**G may each provide similar functionality to the vehicle **110**. FIG. **1**A depicts the vehicle **110** and vehicles **104**A-**104**G as a network of connected vehicles. As used herein, "connected vehicle" refers to a vehicle that is actively connected to edge devices, other vehicles, and/or a cloud server via a network through V2X communication comprising V21, V2C, C2V and/or V2V communications. For example, the vehicle **110** and the vehicles **104**A-**104**G are connected vehicles that include communication circuitry (and other hardware/software providing such capabilities installed thereon) which is capable of wireless communication (e.g., V2X, V21, V2V, etc.) that enables active connections to other vehicles and/or communication devices. As an example, vehicles **110**, **104**A-**104**G communicate with each other using vehicle-to-vehicle (V2V) and communicate to the remote cloud and/or the computer system **140** (or edge server) through the and vehicle-to-cloud (V2C) communication. Accordingly, the vehicle **110**, vehicles **104**A-**104**G, and the computer system **140** being within the same vicinity can be considered a hub of the vehicular knowledge network system **100**. Generally, vehicular knowledge network system **100** supports several functions, including, but not limited to: executing a knowledge cycle (e.g., including creating knowledge), as disclosed herein; communicating requests to knowledge nodes (e.g., vehicles **110**, **104**A-**104**G) for one or more instances of

knowledge; forwarding the requests toward appropriate knowledge nodes, which are expected to have the requested knowledge (e.g., nodes closer to the geographical region), based on contextual features; communicating responses to the requests from other knowledge nodes if it has the requested knowledge in its own knowledge base or from edge server; and communicating the requested knowledge to communication points and knowledge nodes within the system **100** based on contextual features. Thus, by implementing aspects of vehicular knowledge networking, the vehicle **110** can have its own knowledge base, which can be shared and/or communicated with a remote cloud and/or computer system **140** (e.g., edge server) and other vehicles **104**A-**104**G.

[0039] According to the embodiments, the vehicle **110** can be configured to implement the vehicular knowledge networking and performance degradation compensation capabilities, as disclosed herein. That is, for example, each vehicle **110** can be equipped to convert vehicle data generated and exchanged among vehicles into knowledge **145** (e.g., an example of knowledge **250**), where the knowledge **145** provides insight regarding traffic events, driving environment, driving conditions, congestion, and the like. Furthermore, the vehicle **110** can utilize knowledge **145** in order to optimize various vehicular applications. For example, in the example of FIG. **1**A, the vehicle **110** can leverage vehicular knowledge networking in order to execute a guidance application. Thus, by implementing guidance application, vehicle **110** can quantify the conditions in their environment, identify the knowledge of the conditions, and leverage the knowledge to generate guidance for the driver to improve vehicle operation.

[0040] In the example of FIG. **1**A, entities in the vehicular knowledge network, namely the vehicle **110**, vehicles **104**A-**104**G, and computer system **140**, can be configured to implement various aspects of vehicular knowledge networking disclosed herein. In one or more embodiments of the present disclosure, functions supporting vehicular knowledge networking and the improved knowledge cycle can be performed as part of a training process, which may be carried out using a computer system **140**. In the example of FIG. **1**A, the computer system **140** is depicted as a server, for example an edge server, within the vehicular knowledge network system **100**. As seen in FIG. **1**A, the computer system **140** can be configured to include a vehicular knowledge networking system **142**, a context analysis system **143**, and a contrasting analysis system **144**. For example, the computer system **140** might include one or more processors, controllers, control modules, or other processing devices, where the vehicular knowledge networking system **142**, the context analysis system **143**, and the contrasting analysis system **144** may be implemented as hardware processor(s). The vehicular knowledge networking system **142**, the context analysis system **143** contrasting analysis system **144** may also be implemented as software on the computer system **140**, such as instructions, machine-readable code, or computer program components. In another example, knowledge networking system **142**, the context analysis system **143**, and the contrasting analysis system **144** may be implemented as a combination of hardware and software.

[0041] The computer system **140** may be an edge server that resides as a backend system relative to vehicles **110**, and **104**A-**104**G. By way of example, knowledge **145** can be created on the computer system **140**, operating as an edge server, using vehicle data and/or information received from connected vehicles, such as vehicles **120** and **104**A-**104**G, for example, as described in connection with FIG. **3**. Subsequently, knowledge **145** can be distributed throughout the vehicular knowledge network system **100**, which can be used for a knowledge-based guidance applications to control vehicular operations. As an illustrative example, FIG. **1**A depicts knowledge **145**, created at computer system **140**, distributed through the communications to vehicle **110** at point P**1**. For instance, once optimization of the knowledge cycle has converged on the computer system **140**, knowledge **145** can be uploaded to a computer system of the vehicle **110**, for example in the form of trained machine learning models, and used for autonomous, semi-autonomous, assisted, or other driving systems to assist operations of vehicle **110** (e.g., autonomously and/or semi-autonomously) as it travels from point P**1** to point P**2**. It should also be appreciated upon studying the present disclosure that in one or more embodiments the functions or elements of computer system **140** (including the vehicular knowledge networking system **142** and the context analysis system **143**) may reside on board a vehicle, such as vehicle **110**. For example, all or part of computer system **140** may reside within vehicle **110** and their functionalities may be performed thereby.

[0042] Entities of the vehicular knowledge network system **100** can be configured to execute context-based knowledge forwarding techniques. Accordingly, the computer system **140** can receive a set contextual features from one or more vehicles (e.g., vehicles **110** and/or **104**A-**104**G), where the set of contextual features represent various conditions of operating environment **102**. For example, vehicles that have previously traversed the operating environment **102** of FIG. **1**A may have leveraged their capabilities (e.g., sensors) to collect vehicle data that was descriptive of the conditions experienced at the time while driving through the roadway **106**, such as traffic flow, vehicle/driver type, congestion, type of objects at the location, risk caused by other drivers, weather conditions, and the like. This vehicle data, representative of a set of contextual features of the operating environment **102**, can be received and further analyzed by the computer system **140** (context analysis system **143**) to provide a "context" for the knowledge that will be created about the section of roadway **106** according to the set of contextual features, as described above in connection with FIG. **2**. That is, for example, the computer system **140** can analyze the vehicle data (e.g., generated by a plurality of vehicles) of a location, in order to generate one or more contextual feature maps (also referred to as a set of contextual features) that infer a context surrounding knowledge corresponding to the contextual features comprised thereof. According to the embodiments disclosed herein, the context for knowledge (e.g., contextual feature maps) can be created concurrently with the knowledge itself, so as to eliminate additional overhead and/or delays when the knowledge is actually needed (e.g., knowledge forwarded to entities of the vehicular knowledge network). In other words, the context that corresponds to an instance of knowledge can be created during its knowledge cycle (e.g., creating the knowledge). The knowledge cycle can be described as the overall steps for creating and/or distributing knowledge in vehicular knowledge networking, such as vehicular knowledge network system **100**. Generally, a knowledge cycle that may be implemented by the vehicular knowledge networking sys-

tem **142** includes several steps, including but not limited to: knowledge creation; knowledge storage, where the created knowledge is stored and placed intelligently such that a high number of vehicles can access and consume it; knowledge networking, which involves developing the network topology and query/distribution of knowledge; knowledge transfer and knowledge composition, which involves refinement of the knowledge such as merge/accumulation of knowledge.

[0043] FIG. **1**A depicts the computer system **140** as an entity implementing aspects of the context-based forwarding, having context analysis system **143** which is configured to execute the context-based knowledge forwarding techniques disclosed herein. Details of the context-based knowledge forwarding are described in U.S. patent application Ser. No. 18/300,367, the disclosure of which is incorporated herein by reference in its entirety.

[0044] Generally, the context analysis system **143** can be configured to perform "knowledge context" related functions of the disclosed embodiments, including: obtaining contextual features specific to a location before knowledge is created; analyzing the contextual features to create contextual feature maps (inferring the context) specific to a location while its knowledge is created; retrieving the right knowledge without additional delay; and preparing knowledge based on its derived context beforehand to maximize the benefits. A design goal of vehicular knowledge networking is to maximize the benefits of its knowledge (e.g., knowledge is useful/utilized by a large number of entities), thus having insight into the context for knowledge can be used to dynamically make knowledge more beneficial, ensuring that the right knowledge is forwarded to an entity in the right context. Therefore, entities in the vehicular knowledge network system **100**, such as vehicle **110**, may leverage potentially "improved" knowledge **145** resulting from an improved knowledge cycle (e.g., optimized by the disclosed improved knowledge cycle techniques). Furthermore, forwarding knowledge based on its context may provide insight regarding the driving environment in a manner that improves guidance of the vehicle through the risky zone thereby improving overall vehicle/driver safety.

[0045] FIG. **1**A depicts knowledge **145**, which is communicated throughout the vehicular knowledge network system **100**, and can be created by a single vehicle and/or group of vehicles (e.g., vehicular micro cloud) cooperatively. Thus, the vehicle **110** and surrounding vehicles **104**A-**104**C can be referred to as knowledge nodes within the vehicular knowledge network system **100**. Alternatively, or in addition, knowledge **145** can be created at the edge (e.g., by a computer system **140**) the through collaboratively collected data from vehicles within the range of the network, such as vehicles **130**, **104**A-**104**G. The knowledge creation can include all the vehicles inside of a group, shown in FIG. **1**A as vehicles **110**, **104**A-**104**G, but might potentially also be extended to surrounding vehicles or a specific region. According to the embodiments, the created knowledge **145** can be further associated with metadata.

[0046] For example, vehicles **110**, **104**A-**104**G can be equipped with on-vehicle sensors that collect real-time data while driving, where the data (e.g., speed, temperature, road conditions, etc.) is pertinent to driving and/or maneuvering operations. This data, also referred to herein as raw sensor data, can then be communicated, stored, analyzed in accordance with various vehicular networking technologies, and analyzed in order to transform the data into knowledge **145**. For instance, the speed at which different vehicles move along a road in a certain location can be collected, by the respective vehicles, over time. The raw sensor data (referred to herein as vehicle data) can be processed in accordance with the disclosed vehicular knowledge networking capabilities to provide meaningful information in the form of knowledge **145** and the contextual features which constitute its corresponding context **146**. Multiple pieces of raw sensor data, possibly from different vehicles **110**, **104**A-**104**G can be used to infer inner relationships or repeating patterns and contextual relevance that may be found in data, thereby extracting insight on this data that can serve as knowledge **145** and its context **146**. For example, the edge server, namely computer system **140**, and the vehicle **110** may have the capabilities to create contextual features maps for operating environment **102**, and extract meaningful contextual information that enables the context analysis system **143** to create context **146** for knowledge **145**.

[0047] In the example of FIG. **1**A, knowledge **145** can be related to a context **146** for a knowledge-based guidance application. For instance, knowledge **145** can provide insight on a type of maneuvering or other vehicle operating conditions that are often experienced by vehicles according to the context **146**, which can include the specific location of the section of roadway **106**. Context **146** can provide insight to static properties for the specific location (and its knowledge) including, but not limited to: the location, road geometry, traffic rules, and the like. Context **146** can also provide insight to dynamic properties for the specific location (and its knowledge) including, but not limited to: traffic flow, vehicle/driver type, congestion, type of objects at the location, risk caused by other drivers, etc. Thus, the context **146** provides a contextual relationship inferring the conditions surrounding location at a time when the knowledge **145** was created.

[0048] Furthermore, the context analysis system **143** can be configured to analyze a query for knowledge based on its context, such that only the knowledge having a similar context is forwarded in response to the query. For example, vehicle **110** can leverage its capabilities (e.g., sensors) to collect vehicle data descriptive of the conditions currently experienced while driving through the roadway **106**. The conditions can be packaged as a query that can be used to retrieve knowledge **145**. In an example, knowledge **145** can be returned to vehicle **110** when the detected conditions are at least substantially similar to, if not identical to, context **146** associated with knowledge **145**. Conditions may be considered substantially similar where the conditions detected by vehicle **110** includes at least a threshold amount (e.g., percentage, number, or the like) of the contextual features included in context **146**. The threshold in some examples may be 80% (e.g., **8** conditions in a case where context **146** contained 10 contextual features), but other thresholds may be used as desired. Thus, for example, current conditions detected by vehicle **110** at point P**1** are descriptive of 80% or more of contextual features included in context **146**, then knowledge **145** may be uploaded to vehicle **110** for providing knowledge-based guidance between to point P**2**. Thus, the vehicular knowledge networking system **100** forms a knowledge network among entities (e.g., vehicles **110**, **104**A-**104**C), where vehicles **110**, **104**A-**104**C can deduce and share knowledge **145** for enhanced driver/vehicle safety applications (e.g., risk rea-

soning) instead of large volumes of raw sensor data and information (which reduces the cost and volume of communication).

[0049] In operation, when the driver of vehicle **110** approaches point P**1** of roadway **106**, vehicle **110** may send a request to the edge server (or cloud), specifying a set of current condition tags based on the vehicle data collected using the capabilities of vehicle **110** to receive knowledge **145** regarding the driving environment **102**. Note that the vehicle data may include information obtained from one or more of vehicles **104**A-**104**G. The set of current condition tags (e.g., a set of contextual features describing the current conditions) of the operating environment **102** is evaluated to retrieve knowledge corresponding to a set of conditions that are substantially similar or identical to the set of current condition tags. For instance, in the operational example, the vehicle **110** can generate a query for knowledge regarding the current conditions at point P**1**, and use its vehicle sensors (e.g., detecting presence of vehicles **104**A-**104**G) to obtain several contextual features associated with the current "context" of operating environment **102**. As a result of sensing presence and/or location of the other vehicles **104**A-**104**G, the vehicle **110** can obtain data regarding the traffic flow of roadway **106**, for example, which is communicated to the computer system **140** as contextual features. These contextual features generated at the time the ego vehicle **130** is requesting knowledge for the intersection (e.g., vehicle is approaching the atypical intersection) are analyzed by the context analysis system **143**. Accordingly, the context analysis system **143** employs its context-based knowledge forwarding capabilities, such that the knowledge **145** corresponding context **146** is retrieved that matches (e.g., substantially similar or identical to) the current context of the query. Receiving knowledge **145** having a context **146** that corresponds to current conditions suggests that the knowledge will be more beneficial for the vehicle **110** to make an accurate risk analysis and initiate an appropriate safety response that is most applicable to the atypical intersection with high traffic. The knowledge **145** can be shared with the vehicle **110** through V2C communications.

[0050] As previously described, the vehicle **110** can then execute knowledge-based guidance applications (such as safety maneuvers) as a result of the knowledge **145** received. Furthermore, due to context-based knowledge forwarding, the knowledge **145** has a specific contextual relationship operating environment **102** such that that the executed maneuvers performed based on knowledge **145** are applicable for the current conditions, or context, of the risk zone. As an example, if the knowledge **145** indicates that operating environment **102** is a risky zone and/or the nearby vehicles **104**A-**104**G are identified as risky user, certain safety maneuvers may be autonomously performed, such as slowing down, because of the risk and the situational context of the driving environment.

[0051] The vehicular knowledge networking system **100** and context-based knowledge forwarding techniques can thus realize enhanced safety applications, such as risk reasoning, based on knowledge of a current traffic environment which improves the vehicle/driver safety by making preventive and proactive decisions to minimize the threat for all vehicles that are and/or will be affected by the riskiness. Furthermore, by distributing knowledge (as opposed to large amounts of raw data) and analyzing context for that knowledge using a distinct pre-process (e.g., contextual feature maps are used to prepare the knowledge cycle beforehand) the knowledge networking system **100** may mitigate large delays and overhead which is not tolerable in time-critical responses.

[0052] In the example of in FIGS. **1**A, a knowledge cycle can involve the computer system **140** collecting vehicle sensor data from, at least, vehicle **110** and performing knowledge creation from that data. Then, during a knowledge creation stage of the knowledge cycle, an Al/ML modeling approach can be applied to the collected data to create knowledge. Knowledge can be created by a single and/or cluster of vehicles cooperatively or it can be created at the edge through collaboratively collected data from vehicles. The knowledge creation includes all the vehicles inside the cluster but might potentially also be extended to surrounding vehicles or a specific region. The created knowledge is associated with a set of knowledge tags and stored in Knowledge Base (KB). The knowledge can be placed on edge/cloud server according to mobility of vehicles approaching the risky zone. The system uses Vehicle-to-Network communication to network the knowledge. The knowledge is transferred to other locations according to geometry features of road sections. The knowledge is composed with another knowledge based on similarity and used parameter is time of day. The knowledge cycle includes all steps, and the performance is beneficial (i.e., knowledge is delivered to more high number of vehicles).

[0053] In some cases, the knowledge-based guidance application may experience performance degradation following execution thereof. For example, guidance executed according to given knowledge may correspond to an expected performance after the guidance is completed, for example, after executing certain maneuvers. However, in some cases, the actual real-world performance of the guidance may deviate from the expected results due to unforeseen conditions not part of the context **146** or conditions of context **146** that were not present in the current conditions. As an illustrative example, as shown in FIG. **1**A, performance of knowledge-based guidance based on knowledge **145** may be an estimate of available driving range. According to context **146**, knowledge **145**, and thus the corresponding guidance, may be associated with an expected driving range estimation (e.g., 145 miles) as an expected performance result. However, after executing the guidance, vehicle **110** may estimate a real-world available driving range based on a current state of charge of it battery that has a discrepancy relative to the expected result (e.g., 50 miles or other discrepancy). The discrepancy represents a performance degradation in the guidance model that leveraged the knowledge **145**, which can result in unpredictability in the guidance and reduce driver acceptance.

[0054] To compensate for the performance degradation, without having to refine the model and knowledge logic, vehicular knowledge network system **100** can be implement performance degradation compensation functionality, as disclosed herein. That is, for example, computer system **140** can receive performance results **148** of performed knowledge-based guidance from vehicle **110**. For example, knowledge **145** can be retrieved based on a current set of contextual features at point P**1** obtained by vehicle **110**, which can be used to provide guidance to vehicle **110** based on the current set of contextual features. After executing the guidance, vehicle **110** can determined performance results **148**,

for example, using the on-board sensor. Performance results **148** can be packaged with the current context **147** and provided to computer system **140**. The current context **147** may be the current set of contextual features used to retrieve knowledge **145**. Computer system **140** can execute contrasting analysis system **144** to analyze the performance results **148** and determine that the performance results **148** differ from expected result associated with the knowledge **145**, which computer system **140** can tag (or otherwise labeled) as a contrasting result. In some embodiments, a difference may be based on a divergence between the expected results and performance results **148** that is outside a defined threshold deviation, for example, plus-or-minus an amount of deviation relative to the expected result (e.g., 5%, 10%, etc. difference between real-world and expected results).

[0055] Once a contrasting result is identified, computer system **140** may be configured (e.g., contrasting analysis system **144**) to execute contrasting behavior analysis to infer contextual factors that may have caused the contrasting result. For example, computer system **140** may identify differences in contextual features between the current set of contextual features relative to the set of contextual features associated with the expected result. For example, the expected result may correspond to context **146** by virtue of association with knowledge **145**. Contrasting analysis system **144** may compare the context **147** to the context **146** and identify any contextual features that are present in context **146** and absent from current context **147** or present in current context **147** and absent from context **146**. These differences in contextual features can be stored as inferred contrasting factors.

[0056] As an illustrative example, as shown in FIG. **1**A, the context **146** may comprise static properties, such as, the specific location of roadway **106**, road geometry, and traffic rules, along with dynamic properties, such as, traffic flow, congestion, type of objects at the location, risk caused by other drivers, and weather conditions. Context **146** may be used to retrieve knowledge **145** and guidance based on knowledge **145** may be associated with an expected result comprising an estimated driving range of N miles. When the guidance is executed by vehicle **110**, vehicle **110** travels along the section of roadway **106** along path **108** to point P**2**. In this case, path **108** may exhibit aggressive driving behavior by weaving through high-traffic congestion, including aggressive changes in speed. At point P**2**, vehicle **110** computes a performance result **148** of the guidance and returns an estimate M miles, which differs from the expected results. Vehicle **110** provides its current context **147**, including path **108**, to computer system **140** along with performance results **148**. Computer system **140** determines performance results **148** is in contrast with the expected result (e.g., a contrasting result) and infers that the path **108** and driving behavior included with path **108** are contrasting factors. In this case, path **108** may be the only contrasting contextual factor, which means that, according to the context-based knowledge forwarding capabilities, knowledge **145** was the correct knowledge for the current context. However, since there were circumstances unforeseen in the model, the performance was sub-optimal. The path **108** and driving behavior included with path **108** may be examples of dynamic features.

[0057] Upon identifying the contrasting behavior, computer system **140** can take actions to mitigate the inferred contrasting behavior as a compensation strategy for the contrasting result (e.g., representative of performance degradation in the model). For example, FIG. **1**B is a schematic diagram of an example environment **150** in which a vehicular knowledge network system **100**, as described above, can be implemented to mitigate performance degradation. The example operating environment **150** includes ego vehicle **120**, and one or more vehicles **105**A-**105**G traveling in a driving environment on a section of roadway **106**. Vehicles **120** and **105**A-**105**G may each provide similar functionality to the vehicle **110**. As described above, in this example, vehicles **120** may retrieve knowledge **145** based on current conditions that are substantially similar as or the identical to context **146**. However, unlike in operating environment **102** above, computer system **140** may have executed its performance degradation compensation capabilities to inferred contrasting behavior from a prior vehicle (e.g., vehicle **110**), as described above. A contrasting behavior, such as that described above in connection with FIG. **1**A, may be included in the current conditions detected by vehicles **120**. Computer system **140** may execute knowledge **145** based on the current conditions being substantially similar or identical to context **146**, as described above. Additionally, context analysis system **143** may be configured to recognize the contrasting behavior from the current conditions. Based on this recognition, along with uploading knowledge **145** to ego vehicle **120**, computer system **140** may be configured to issue one or more additional guidance, in the form of control commands **160**A-**160**D, to ego vehicle **120** and/or surrounding vehicles **105**A-**105**D.

[0058] The additional guidance (or compensation guidance as sometimes referred to herein) may be configured to guide the ego vehicle **120** and/or vehicles **105**A-**105**D, autonomously or semi-autonomously, to mitigate the inferred contrasting behavior of vehicles **120**. For example, in the case of aggressive driving behavior of path **108** exhibited by vehicles **120**, control commands **160**B-**160**D may be configured to coordinate the vehicles **105**A-**105**D into a platoon of vehicles that reduce the likely hood of vehicle **120** executing aggressive behavior. As another example, alone or in combination of the coordination, control command **160**A may be issued that provides guidance to reduce speed or weaving maneuvers. The control commands **160**A-**160**D may be packages as part of knowledge **145**, for example, by updating knowledge **145** according to the contrasting behavior.

[0059] Additional examples and explanation of mitigation techniques can be found, for example, in U.S. application Ser. No. 17/959,866, filed on Oct. 4, 2022, entitled "SYSTEMS AND METHODS TO MANAGE DRIVERS UNDER ABNORMAL DRIVING;" U.S. application Ser. No. 17/005,258, filed on Aug. 27, 2020, entitled "SYSTEMS AND METHODS TO GROUP AND MOVE VEHICLES COOPERATIVELY TO MITIGATE ANOMALOUS DRIVING BEHAVIOR;" and U.S. Pat. No. 11,414,088, filed on Jan. 16, 2020, entitled "ANOMALOUS DRIVER DETECTION SYSTEM," the disclosures of which are incorporated herein by reference in their entirety.

[0060] The systems and methods disclosed herein may be implemented with any of a number of different vehicles and vehicle types. For example, the systems and methods disclosed herein may be used with automobiles, trucks, motorcycles, recreational vehicles and other like on-or off-road vehicles. In addition, the principals disclosed herein may also extend to other vehicle types as well. An example

hybrid electric vehicle (HEV) in which embodiments of the disclosed technology may be implemented is illustrated in FIG. **3**. Although the example described with reference to FIG. **3** is a hybrid type of vehicle, the systems and methods for performance degradation compensation can be implemented in other types of vehicle including gasoline- or diesel-powered vehicles, fuel-cell vehicles, electric vehicles, or other vehicles.

[0061] FIG. **3** illustrates a drive system of an example vehicle **300** that may include an internal combustion engine **314** and one or more electric motors **322** (which may also serve as generators) as sources of motive power. Vehicle **300** may be an example implementation of vehicle **110**, **120**, **104**A-**104**G and/or **105**A-**105**G of FIGS. **1**A and **1**B. Driving force generated by the internal combustion engine **314** and motors **322** can be transmitted to one or more wheels **334** via a torque converter **316**, a transmission **318**, a differential gear device **328**, and a pair of axles **330**.

[0062] As an HEV, vehicle **300** may be driven/powered with either or both of engine **314** and the motor(s) **322** as the drive source for travel. For example, a first travel mode may be an engine-only travel mode that only uses internal combustion engine **314** as the source of motive power. A second travel mode may be an EV travel mode that only uses the motor(s) **322** as the source of motive power. A third travel mode may be an HEV travel mode that uses engine **314** and the motor(s) **322** as the sources of motive power. In the engine-only and HEV travel modes, vehicle **300** relies on the motive force generated at least by internal combustion engine **314**, and a clutch **315** may be included to engage engine **314**. In the EV travel mode, vehicle **300** is powered by the motive force generated by motor **322** while engine **314** may be stopped and clutch **315** disengaged.

[0063] Engine **314** can be an internal combustion engine such as a gasoline, diesel or similarly powered engine in which fuel is injected into and combusted in a combustion chamber. A cooling system **312** can be provided to cool the engine **314** such as, for example, by removing excess heat from engine **314**. For example, cooling system **312** can be implemented to include a radiator, a water pump and a series of cooling channels. In operation, the water pump circulates coolant through the engine **314** to absorb excess heat from the engine. The heated coolant is circulated through the radiator to remove heat from the coolant, and the cold coolant can then be recirculated through the engine. A fan may also be included to increase the cooling capacity of the radiator. The water pump, and in some instances the fan, may operate via a direct or indirect coupling to the driveshaft of engine **314**. In other applications, either or both the water pump and the fan may be operated by electric current such as from battery **344**.

[0064] An output control circuit **314**A may be provided to control drive (output torque) of engine **314**. Output control circuit **314**A may include a throttle actuator to control an electronic throttle valve that controls fuel injection, an ignition device that controls ignition timing, and the like. Output control circuit **314**A may execute output control of engine **314** according to a command control signal(s) supplied from an electronic control unit **350**, described below. Such output control can include, for example, throttle control, fuel injection control, and ignition timing control.

[0065] Motor **322** can also be used to provide motive power in vehicle **300** and is powered electrically via a battery **344**. Battery **344** may be implemented as one or more batteries or other power storage devices including, for example, lead-acid batteries, nickel-metal hydride batteries, lithium ion batteries, capacitive storage devices, and so on. Battery **344** may be charged by a battery charger **345** that receives energy from internal combustion engine **314**. For example, an alternator or generator may be coupled directly or indirectly to a drive shaft of internal combustion engine **314** to generate an electrical current as a result of the operation of internal combustion engine **314**. A clutch can be included to engage/disengage the battery charger **345**. Battery **344** may also be charged by motor **322** such as, for example, by regenerative braking or by coasting during which time motor **322** operate as generator.

[0066] Motor **322** can be powered by battery **344** to generate a motive force to move the vehicle and adjust vehicle speed. Motor **322** can also function as a generator to generate electrical power such as, for example, when coasting or braking. Battery **344** may also be used to power other electrical or electronic systems in the vehicle. Motor **322** may be connected to battery **344** via an inverter **342**. Battery **344** can include, for example, one or more batteries, capacitive storage units, or other storage reservoirs suitable for storing electrical energy that can be used to power motor **322**. When battery **344** is implemented using one or more batteries, the batteries can include, for example, nickel metal hydride batteries, lithium ion batteries, lead acid batteries, nickel cadmium batteries, lithium ion polymer batteries, and other types of batteries.

[0067] An electronic control unit **350** (described below) may be included and may control the electric drive components of the vehicle as well as other vehicle components. For example, electronic control unit **350** may control inverter **342**, adjust driving current supplied to motor **322**, and adjust the current received from motor **322** during regenerative coasting and breaking. As a more particular example, output torque of the motor **322** can be increased or decreased by electronic control unit **350** through the inverter **342**.

[0068] A torque converter **316** can be included to control the application of power from engine **314** and motor **322** to transmission **318**. Torque converter **316** can include a viscous fluid coupling that transfers rotational power from the motive power source to the driveshaft via the transmission. Torque converter **316** can include a conventional torque converter or a lockup torque converter. In other embodiments, a mechanical clutch can be used in place of torque converter **316**.

[0069] Clutch **315** can be included to engage and disengage engine **314** from the drivetrain of the vehicle. In the illustrated example, a crankshaft **332**, which is an output member of engine **314**, may be selectively coupled to the motor **322** and torque converter **316** via clutch **315**. Clutch **315** can be implemented as, for example, a multiple disc type hydraulic frictional engagement device whose engagement is controlled by an actuator such as a hydraulic actuator. Clutch **315** may be controlled such that its engagement state is complete engagement, slip engagement, and complete disengagement complete disengagement, depending on the pressure applied to the clutch. For example, a torque capacity of clutch **315** may be controlled according to the hydraulic pressure supplied from a hydraulic control circuit (not illustrated). When clutch **315** is engaged, power transmission is provided in the power transmission path between the crankshaft **332** and torque converter **316**. On the other hand, when clutch **315** is disengaged, motive power

from engine **314** is not delivered to the torque converter **316**. In a slip engagement state, clutch **315** is engaged, and motive power is provided to torque converter **316** according to a torque capacity (transmission torque) of the clutch **315**.

[0070] As alluded to above, vehicle **300** may include an electronic control unit **350**. Electronic control unit **350** may include circuitry to control various aspects of the vehicle operation. Electronic control unit **350** may include, for example, a microcomputer that includes a one or more processing units (e.g., microprocessors), memory storage (e.g., RAM, ROM, etc.), and I/O devices. The processing units of electronic control unit **350**, execute instructions stored in memory to control one or more electrical systems or subsystems **358** in the vehicle. Electronic control unit **350** can include a plurality of electronic control units such as, for example, an electronic engine control module, a powertrain control module, a transmission control module, a suspension control module, a body control module, and so on. As a further example, electronic control units can be included to control systems and functions such as doors and door locking, lighting, human-machine interfaces, cruise control, telematics, braking systems (e.g., ABS or ESC), battery management systems, and so on. These various control units can be implemented using two or more separate electronic control units, or using a single electronic control unit.

[0071] In the example illustrated in FIG. **3**, electronic control unit **350** receives information from a plurality of sensors included in vehicle **300**. For example, electronic control unit **350** may receive signals that indicate vehicle operating conditions or characteristics, or signals that can be used to derive vehicle operating conditions or characteristics. These may include, but are not limited to accelerator operation amount (A_{CC}), a revolution speed (N_E), of internal combustion engine **314** (engine RPM), a rotational speed (N_{MG}) of the motor **322** (motor rotational speed), and vehicle speed (N_V). These may also include torque converter **316** output (N_T) (e.g., output amps indicative of motor output), brake operation amount/pressure (B), battery (SOC) (i.e., the charged amount for battery **344** detected by an SOC sensor). Accordingly, vehicle **300** can include a plurality of sensors **352** that can be used to detect various conditions internal or external to the vehicle and provide sensed conditions to engine control unit **350** (which, again, may be implemented as one or a plurality of individual control circuits). In one embodiment, sensors **352** may be included to detect one or more conditions directly or indirectly such as, for example, fuel efficiency (E_F), motor efficiency (E_{MG}), hybrid (internal combustion engine **314**+MG **322**) efficiency, acceleration (A_{CC}), etc.

[0072] In some embodiments, one or more of the sensors **352** may include their own processing capability to compute the results for additional information that can be provided to electronic control unit **350**. In other embodiments, one or more sensors may be data-gathering-only sensors that provide only raw data to electronic control unit **350**. In further embodiments, hybrid sensors may be included that provide a combination of raw data and processed data to electronic control unit **350**. Sensors **352** may provide an analog output or a digital output.

[0073] Sensors **352** may be included to detect not only vehicle conditions but also to detect external conditions as well. Sensors that might be used to detect external conditions can include, for example, sonar, radar, lidar or other vehicle proximity sensors, and cameras or other image sensors. Image sensors can be used to detect objects in an environment surrounding vehicle **300**, for example, traffic signs indicating a current speed limit, road curvature, obstacles, surrounding vehicles, and so on. Still other sensors may include those that can detect road grade. While some sensors can be used to actively detect passive environmental objects, other sensors can be included and used to detect active objects such as those objects used to implement smart roadways that may actively transmit and/or receive data or other information.

[0074] The example of FIG. **3** is provided for illustration purposes only as one example of vehicle systems with which embodiments of the disclosed technology may be implemented. One of ordinary skill in the art reading this description will understand how the disclosed embodiments can be implemented with this and other vehicle platforms.

[0075] FIG. **4** illustrates an example architecture for knowledge networking system **400** in accordance with one embodiment of the systems and methods described herein. Referring now to FIG. **4**, in this example, knowledge networking system **400** includes a performance degradation compensation circuit **410**, a plurality of sensors **452** and a plurality of vehicle systems **458**. Sensors **452** (such as sensors **352** described in connection with FIG. **3**) and vehicle systems **358** (such as subsystems **358** described in connection with FIG. **3**) can communicate with performance degradation compensation circuit **410** via a wired or wireless communication interface. Although sensors **452** and vehicle systems **458** are depicted as communicating with hierarchical federated learning circuit **410**, they can also communicate with each other as well as with other vehicle systems. Performance degradation compensation circuit **410** can be implemented as an ECU or as part of an ECU such as, for example electronic control unit **350**. In other embodiments, performance degradation compensation circuit **410** can be implemented independently of the ECU.

[0076] Performance degradation compensation circuit **410** in this example includes a communication circuit **401**, a decision circuit **403** (including a processor **406** and memory **408** in this example) and a power supply **412**. Components of performance degradation compensation circuit **410** are illustrated as communicating with each other via a data bus, although other communication in interfaces can be included. Performance degradation compensation circuit **410** in this example also includes client **405** that can be operated to connect to an edge server of a network **490** to contribute to provide contextual factors, such as current conditions (e.g., representative of contextual factors); download knowledge (e.g., knowledge **145** of FIG. **1**A) for use by vehicle systems **458**; communicate results (e.g., performance results **148** of FIG. **1**A), etc.

[0077] The decision circuit **403** can comprises a context engine, a knowledge cycle engine, and contrasting results engine. For example, the context engine may be executed by processor **406** for performing the context-based knowledge forwarding functions described above, including but not limited to: analyzing contextual features; constructing contextual feature maps; aggregating contextual features; contextual feature matching; determining a path for knowledge with specific contextual features. The knowledge cycle engine may be executed by processor **406** for performing knowledge cycle functions with contextual aspects, including but not limited to: executing stages of a knowledge cycle; inferring the contextual feature map of each step of

knowledge cycle; and determine a path for knowledge with specific contextual features. The contrasting results engine may be executed by processor **406** for performing contrasting analysis functions with, including but not limited to: detecting contrasting results; identifying contrasting behavior that may have caused the contrasting result; and providing guidance to mitigate contrasting behaviors, thereby compensating for the contrasting result.

[0078] Processor **406** can include one or more GPUs, CPUs, microprocessors, or any other suitable processing system. Processor **406** may include a single core or multicore processors. The memory **408** may include one or more various forms of memory or data storage (e.g., flash, RAM, etc.) that may be used to store instructions and variables for processor **406** as well as any other suitable information, such as, one or more of the following elements: position data; vehicle speed data; risk and mitigation data, along with other data as needed. Memory **408** can be made up of one or more modules of one or more different types of memory, and may be configured to store data and other information as well as operational instructions that may be used by the processor **406** to performance degradation compensation circuit **410**. For example, memory **408** may store instructions that, when executed by processor **406**, perform functionality described in connection with FIGS. **1**A and **1**B above.

[0079] Although the example of FIG. **4** is illustrated using processor and memory circuitry, as described below with reference to circuits disclosed herein, decision circuit **403** can be implemented utilizing any form of circuitry including, for example, hardware, software, or a combination thereof. By way of further example, one or more processors, controllers, ASICs, PLAS, PALs, CPLDs, FPGAs, logical components, software routines or other mechanisms might be implemented to make up a performance degradation compensation circuit **410**.

[0080] Communication circuit **401** includes either or both a wireless transceiver circuit **402** with an associated antenna **414** and a wired I/O interface **404** with an associated hardwired data port (not illustrated). Communication circuit **401** can provide for vehicle-to-everything (V2X) and/or vehicle-to-vehicle (V2V) communications capabilities, allowing performance degradation compensation circuit **410** to communicate with edge devices, network cloud servers and cloud-based databases, and/or other vehicles via network **490**. For example, V2X communication capabilities allows performance degradation compensation circuit **410** to communicate with edge/cloud servers, roadside infrastructure (e.g., such as roadside equipment/roadside unit, which may be a vehicle-to-infrastructure (V21)-enabled street light or cameras, for example), etc. Performance degradation compensation circuit **410** may also communicate with other connected vehicles over vehicle-to-vehicle (V2V) communications.

[0081] As this example illustrates, communications with performance degradation compensation circuit **410** can include either or both wired and wireless communications circuits **401**. Wireless transceiver circuit **402** can include a transmitter and a receiver (not shown) to allow wireless communications via any of a number of communication protocols such as, for example, Wi-Fi, Bluetooth, near field communications (NFC), Zigbee, and any of a number of other wireless communication protocols whether standardized, proprietary, open, point-to-point, networked or otherwise. Antenna **414** is coupled to wireless transceiver circuit **402** and is used by wireless transceiver circuit **402** to transmit radio signals wirelessly to wireless equipment with which it is connected and to receive radio signals as well. These RF signals can include information of almost any sort that is sent or received by performance degradation compensation circuit **410** to/from other entities such as sensors **452** and vehicle systems **458**.

[0082] Wired I/O interface **404** can include a transmitter and a receiver (not shown) for hardwired communications with other devices. For example, wired I/O interface **404** can provide a hardwired interface to other components, including sensors **452** and vehicle systems **458**. Wired I/O interface **404** can communicate with other devices using Ethernet or any of a number of other wired communication protocols whether standardized, proprietary, open, point-to-point, networked or otherwise.

[0083] Power supply **412** can include one or more of a battery or batteries (such as, e.g., Li-ion, Li-Polymer, NiMH, NiCd, NiZn, and NiH2, to name a few, whether rechargeable or primary batteries,), a power connector (e.g., to connect to vehicle supplied power, etc.), an energy harvester (e.g., solar cells, piezoelectric system, etc.), or it can include any other suitable power supply.

[0084] Sensors **452** can include, for example, sensors **352** such as those described above with reference to the example of FIG. **3**. Sensors **452** can include additional sensors that may or may not otherwise be included on a standard vehicle with which the knowledge networking system **400** is implemented. In the illustrated example, sensors **452** include vehicle acceleration sensors **418**, vehicle speed sensors **420**, wheelspin sensors **416** (e.g., one for each wheel), accelerometers such as a 4-axis accelerometer **422** to detect roll, pitch and yaw of the vehicle, environmental sensors **428** (e.g., to detect salinity or other environmental conditions), and proximity sensor **430** (e.g., sonar, radar, lidar or other vehicle proximity sensors). Additional sensors **432** can also be included as may be appropriate for a given implementation of knowledge networking system **400**.

[0085] System **400** may be equipped with one or more image sensors **460**. These may include front facing image sensors, side facing image sensors, and/or rear facing image sensors. Image sensors may capture information which may be used in detecting not only vehicle conditions but also detecting conditions external to the vehicle as well. Image sensors that might be used to detect external conditions can include, for example, cameras or other image sensors configured to capture data in the form of sequential image frames forming a video in the visible spectrum, near infrared (IR) spectrum, IR spectrum, ultra violet spectrum, etc. Image sensors **460** can be used to, for example, to detect objects in an environment surrounding a vehicle comprising knowledge networking system **400**, for example, surrounding vehicles, roadway environment, road lanes, road curvature, obstacles, and so on. For example, a one or more image sensors **460** may capture images of surrounding vehicles in the surrounding environment. As another example, object detecting and recognition techniques may be used to detect objects and environmental conditions, such as, but not limited to, road conditions, surrounding vehicle behavior (e.g., driving behavior and the like), and the like. Additionally, sensors may estimate proximity between vehicles. For instance, the image sensors **460** may include cameras that may be used with and/or integrated with other proximity sensors **430** such as LIDAR sensors or any other sensors

capable of capturing a distance. As used herein, a sensor set of a vehicle may refer to sensors **452**.

[0086] Vehicle systems **458**, for example, systems and subsystems **358** described above with reference to the example of FIG. **3**, can include any of a number of different vehicle components or subsystems used to control or monitor various aspects of the vehicle and its performance. In this example, the vehicle systems **458** includes a vehicle positioning system **472**; engine control circuits **476** to control the operation of engine (e.g. internal combustion engine **314** and/or motors **322**); object detection system **478** to perform image processing such as object recognition and detection on images from image sensors **460**, proximity estimation, for example, from image sensors **460** and/or proximity sensors, etc. for use in other vehicle systems; vehicle display and interaction system **474** (e.g., vehicle audio system for broadcasting notifications over one or more vehicle speakers), vehicle display system and/or the vehicle dashboard system), and other vehicle systems **482** (e.g., Advanced Driver-Assistance Systems (ADAS), autonomous or semi-autonomous driving systems **480**, such as forward/rear collision detection and warning systems, pedestrian detection systems, autonomous or semi-autonomous driving systems, and the like).

[0087] Autonomous or semi-autonomous driving systems **480** can be operatively connected to the various vehicle systems **458** and/or individual components thereof. For example, autonomous or semi-autonomous driving systems **480** can send and/or receive information from the various vehicle systems **458** to control the movement, speed, maneuvering, heading, direction, etc. of the vehicle. The autonomous or semi-autonomous driving systems **480** may control some or all of these vehicle systems **458** and, thus, may be semi- or fully autonomous. In some examples, guidance, either knowledge-based guidance and/or compensation guidance, can be provided to autonomous or semi-autonomous driving systems **480** and used to control vehicle systems **458** and/or individual components thereof.

[0088] Network **490** may be a conventional type of network, wired or wireless, and may have numerous different configurations including a star configuration, token ring configuration, or other configurations. Furthermore, the network **490** may include a local area network (LAN), a wide area network (WAN) (e.g., the Internet), or other interconnected data paths across which multiple devices and/or entities may communicate. In some embodiments, the network may include a peer-to-peer network. The network may also be coupled to or may include portions of a telecommunications network for sending data in a variety of different communication protocols. In some embodiments, the network **490** includes Bluetooth® communication networks or a cellular communications network for sending and receiving data including via short messaging service (SMS), multimedia messaging service (MMS), hypertext transfer protocol (HTTP), direct data connection, wireless application protocol (WAP), e-mail, DSRC, full-duplex wireless communication, mmWave, Wi-Fi (infrastructure mode), Wi-Fi (ad-hoc mode), visible light communication, TV white space communication and satellite communication. The network may also include a mobile data network that may include 3G, 4G, 5G, LTE, LTE-V2V, LTE-V21, LTE-V2X, LTE-D2D, VOLTE, 5G-V2X or any other mobile data network or combination of mobile data networks. Further, the network **490** may include one or more IEEE 802.11 wireless networks.

[0089] In some embodiments, the network **490** includes a V2X network (e.g., a V2X wireless network). The V2X network is a communication network that enables entities such as elements of the operating environment to wirelessly communicate with one another via one or more of the following: Wi-Fi; cellular communication including 3G, 4G, LTE, 5G, etc.; Dedicated Short Range Communication (DSRC); millimeter wave communication; etc. As described herein, examples of V2X communications include, but are not limited to, one or more of the following: Dedicated Short Range Communication (DSRC) (including Basic Safety Messages (BSMs) and Personal Safety Messages (PSMs), among other types of DSRC communication); Long-Term Evolution (LTE); millimeter wave (mmWave) communication; 3G; 4G; 5G; LTE-V2X; 5G-V2X; LTE-Vehicle-to-Vehicle (LTE-V2V); LTE-Device-to-Device (LTE-D2D); Voice over LTE (VOLTE); etc. In some examples, the V2X communications can include V2V communications, Vehicle-to-Infrastructure (V21) communications, Vehicle-to-Network (V2N) communications or any combination thereof.

[0090] Examples of a wireless message (e.g., a V2X wireless message) described herein include, but are not limited to, the following messages: a Dedicated Short Range Communication (DSRC) message; a Basic Safety Message (BSM); a Long-Term Evolution (LTE) message; an LTE-V2X message (e.g., an LTE-Vehicle-to-Vehicle (LTE-V2V) message, an LTE-Vehicle-to-Infrastructure (LTE-V21) message, an LTE-V2N message, etc.); a 5G-V2X message; and a millimeter wave message, etc.

[0091] During operation, performance degradation compensation circuit **410** can receive information from various vehicle sensors to determine conditions of a driving environment, which can be used to construct contextual features, as described above in connection with FIGS. **1A-2**. Communication circuit **401** can be used to transmit and receive information between performance degradation compensation circuit **410** and sensors **452**, and performance degradation compensation circuit **410** and vehicle systems **458**. Also, sensors **452** may communicate with vehicle systems **458** directly or indirectly (e.g., via communication circuit **401** or otherwise).

[0092] In various embodiments, communication circuit **401** can be configured to receive data and other information from edge or cloud serves vis client **405**, which can be communicated to vehicle systems **458** for performing vehicle operations. For example, knowledge can be received from an edge server via communication circuit **401** and provided to machine learning model, stored in memory, to execute a guidance application via one or more subsystems **458**. For example, autonomous or semi-autonomous driving systems **480** may comprise a machine learning model that controls vehicle operations according to knowledge received.

[0093] FIG. **5** is a flow chart illustrating example operations for compensation of performance degradation in vehicular knowledge networking in accordance with embodiments disclosed herein. Process **500** may be implemented as instructions, for example, stored on in memory, that when executed by one or more processors perform one or more operations of process **500**. In one example, process

500 may be implemented as instructions stored on performance degradation compensation circuit **410**, that when executed by one or more processors, perform one or more operations of process **500**. In another example, one or more operations of process **500** may be performed by an edge server, such as computer system **140** of FIG. **1**. Furthermore, one or more operations of process **500** can be executed by performance degradation compensation circuit **410**, while other operations are performed by computer system **140**.

[0094] At operation **510**, a contrasting result can be detected based on a performance result of guidance compared to an expected result of the guidance. The performance of the guidance may be performance results after a vehicle has executed the guidance in a first driving environment. The guidance may be associated with a second driving environment that is substantially the same or identical to (e.g., corresponds to) the first driving environment. In some examples, the guidance may be knowledge-based guidance that is based on knowledge associated with a second driving environment that is substantially the same or identical to the first driving environment, as described above in connection with FIG. **1**A.

[0095] For example, a vehicle may collect vehicle data using sensors (e.g., sensors **452**) and/or vehicle subsystems (e.g., vehicle systems **458**) to obtain current conditions of a first driving environment while the vehicle travels in the first driving environment. The current conditions can be provided as a first set of contextual features of the first driving environment. The collected data may be from the vehicle itself and/or other connected vehicles (e.g., vehicular micro cloud or other peer-to-peer network). In some examples, an edge server may also communicate current contextual features to a vehicle. Contextual features can be static features, such as, but not limited to, a location, road geometry, traffic rules, and the like. Contextual features can be dynamic features, such as, but not limited to, traffic flow, vehicle/driver type, congestion, type of objects at the location, risk caused by other drivers, etc.

[0096] The current contextual features can be used to retrieve knowledge from an edge server, which can be utilized by a guidance model provide guidance to a vehicle subsystem for controlling vehicular operations. For example, the vehicle can compose a query, including the first set of contextual features, which can be provided to an edge server. The edge server can access a database of knowledge according to the first set of contextual features, locate the second set of contextual features (e.g., context **146** of FIG. **1**A) that is substantially the same or identical to the first set of contextual features (e.g., at least a threshold amount of overlap of contextual features, as described above in connection with FIG. **1**A), and retrieve knowledge (e.g., knowledge **145** of FIG. **1**A) associated with the second set of contextual features. The knowledge can be provided to a computer (e.g., performance degradation compensation circuit **410**), which executes guidance according to the knowledge (e.g., performs some vehicle operation based on the knowledge).

[0097] The performance of the guidance can be measured to provide a performance result and used to determine whether or not the performance differs from an expected result associated with the knowledge. For example, the performance can be measured using sensors **452** and/or vehicle systems **458** and then stored as a performance result. This result can be compared, at the vehicle or at an edge server, to the expected result of the knowledge-based guidance. If the result differs, for example, by being outside a defined deviation of the expected result, the performance result can be tagged or otherwise labeled as a contrasting result.

[0098] At operation **520**, contrasting behavior of the first vehicle that may have caused the contrasting result is identified, for example, based on a comparison between the first and second driving environments. For example, the first driving environment can be compared to the second driving environment to infer factors experience by the vehicle that may have caused the contrasting result. More particularly, for example, operation **520** may include identifying differences between contextual features of the first set of contextual features relative to the second set of contextual features associated with the expected result. For example, contextual features that are present in one set and absent from the other can be identified as contrasting factors. In various examples, the contrasting factors may comprise dynamic factors, as described above.

[0099] At operation **530**, guidance can be generated configured to mitigate the inferred contrasting behavior, which can compensate for the contrasting results. For example, operation **530** may include generating a second guidance (also referred to as a compensation guidance) that strives to mitigate the contrasting behavior recognized in a set of contextual features obtained from another vehicle. The second guidance can be generated so as to reduce the likelihood that the other vehicle performs the contrasting behavior and/or coordinates surrounding vehicles to reduce such likelihood.

[0100] In an example use case, process **500** can be used to compensate for performance degradation in driving range estimation, for example, in BEVs or HEVs, as described above in connection with FIGS. **1**A and **1**B. For example, vehicle **110** may execute operation **510** to infer contextual features at a point P**1** (e.g., highway with medium traffic congestion and vehicle **110** is a passenger car traveling at 65 mph) and retrieve, from computer system **140**, knowledge **145** according to context **146** that may be substantially the same or identical to the inferred contextual features. Vehicle **110** may execute guidance according to knowledge **145**, and compute current results of the guidance. The current performance results, for example, estimate of available driving range on electrical power, can be compared to excepted results to detect contrasting results. Upon detecting contrasting results, in one example of operation **520**, vehicle **110** may compare the inferred contextual features to the context **146** and identify contrasting factors. In another case, performance results **148** and context **147** can be provided to **140**, which performs operation **520**. In either case, contrasting factors may be determined as aggressive driving behavior due to path **108** (e.g., intermittent speeding and weaving between lanes), which corresponds to the contrasting result. Using the inferred contrasting factors, at operation **530**, guidance can be generated in the form of speed and lane change advisories to one or more vehicles to coordinate vehicles into a platoon designed to avoid speeding and weaving by vehicles. This coordination may be communicated from computer system **140** or from one or more vehicles in the environment.

[0101] In another use case, process **500** can be used to compensate for performance degradation in contrasting arrival times according to a mapped guidance, for example,

by a navigation system. For example, a vehicle **110** may execute operation **510** to infer (e.g., urban area with medium traffic congestion and ego vehicle is a passenger car traveling at 45 mph) and retrieve, from an edge server, knowledge according to a context that may be the same or similar to the inferred contextual features. The guidance may be provided as a navigation path displayed on a map presented on interaction system **474**. Upon arriving at the destination, the performance of the navigation can computed current, for example, as an amount of time between departure and arrival. The time to arrival can be compared to excepted results arrival time to detect a contrasting results. Upon detecting contrasting results, at operation **520**, the inferred contextual features can be compared to the context used to retrieve the knowledge and identify contrasting factors. In an example, contrasting factors may be that the vehicle performed multiple turn loops, for example, due to confusion at intersections, which lead to the contrasting results. Using the inferred contrasting factors, at operation **530**, guidance can be generated in the form of increased amount of micro-level and increased detailed map guidance to mitigate confusion and decrease arrival time.

[0102] FIG. **6** is flow chart illustrating an example process for performance degradation compensation in vehicular knowledge networking in accordance with embodiments disclosed herein. Process **600** may be implemented as instructions, for example, stored on in memory, that when executed by one or more processors perform one or more operations of process **600**. In one example, process **600** may be implemented as instructions stored on performance degradation compensation circuit **410**, that when executed by one or more processors to perform one or more operations of process **500**. In another example, one or more operations of process **600** may be performed by an edge server, such as computer system **140** of FIG. **1**. Furthermore, one or more operations of process **600** can be executed by performance degradation compensation circuit **410**, while other operations are performed by computer system **140**.

[0103] At block **602**, guidance is executed by a vehicle and performance results can be computed, for example, based on vehicle data collected by sensors and/or vehicles subsystems (e.g., sensors **452** and/or vehicle systems **458**). For example, as described above in connection with FIGS. **1**A and **5**, knowledge-based guidance can be obtained based on current conditions (e.g., current set of contextual features) inferred from vehicle data collected by the vehicle.

[0104] At determination block **604**, a determination is made as to whether the performance results computed at block **602** is a contrasting results. For example, as described in connection with FIGS. **1**A and **5**, the performance result is compared to an expected result of the knowledge-based guidance, where the knowledge-based guidance is associated with a set of contextual features that is substantially similar or identical to the current conditions. Determination block **604** determines whether the performance results differ from the expected results, representative of a performance degradation in the guidance model that provided the knowledge-based guidance. If the performance results do not differ (e.g., no at determination block **604**), process **600** returns to block **602** for a next execution of the knowledge-based guidance, either by the same or a different vehicle.

[0105] However, if the performance result does differ, for example, are outside a defined deviation from the expected results (e.g., yes at determination block **604**), process **600** proceeds to block **606** where the contrasting result is analyzed. In examples, block **604** examines at the objective function. For example, block **604** checks if there are contrasting results in the performance results for similar driving environments, e.g., in environment performance was as expected, but in another performance differs from expectations. Block **608**, described below in more details, can be more general and looks for the origin of the contrasting results (e.g., the contextual factors that drive the contrasting results).

[0106] At block **608**, contextual factors (e.g., driving behaviors) that may have caused the contrasting result are inferred. For example, differences between contextual features of the current conditions relative to the set of contextual features associated with the expected result can be inferred. In other words, contextual features that are present in the current conditions, but absent from the set of contextual features associated with the expected result can be inferred as a factor. Similarly, contextual features that are absent from the current conditions, but present in the set of contextual features associated with the expected result can be inferred as a factor.

[0107] At block **610**, subsequent vehicles can be guided according to compensation guidance to mitigate the inferred contextual factors. Subsequent vehicles may refer to vehicles that experience the current conditions from block **610** or substantially similar conditions to the current conditions from block **610** at time executing block **608**. The compensation guidance can be configured to mitigate the inferred factor (e.g., driving behavior), which can compensate for the contrasting results. For example, block **610** may include generating guidance to reduce the likelihood that the other vehicle performs the contrasting behavior and/or coordinates surrounding vehicles to reduce such likelihood.

[0108] At determination block **612**, a determination is made as to whether or not the performance of the guidance has improved. For example, the performance of guidance at block **610** can be computed in a manner similar to that described for block **602**. A difference between the expected result and the performance result of block **612** can be computed, which can be compared to a prior difference in performance result (e.g., the performance computed in block **602**) to expected result. If the difference at determination block **612** is less than the prior difference, then the performance may be considered as improving and process **600** returns to block **602**. Whereas, if the performance does not improve, process **600** returns to block **610** as feedback that adjusts the compensation guidance to further improve performance.

[0109] While examples provided herein, for example, such as described in connection with FIGS. **5** and **6**, are described as detecting contrasting results from knowledge-based guidance, the scope of the embodiments is not intended to be limited to knowledge-based guidance only. Embodiments disclosed herein may be able to detect contrasting results from any guidance or model, not only knowledge-based guidance.

[0110] As used herein, the terms circuit and component might describe a given unit of functionality that can be performed in accordance with one or more embodiments of the present application. As used herein, a component might be implemented utilizing any form of hardware, software, or a combination thereof. For example, one or more processors, controllers, ASICs, PLAs, PALs, CPLDs, FPGAs, logical

components, software routines or other mechanisms might be implemented to make up a component. Various components described herein may be implemented as discrete components or described functions and features can be shared in part or in total among one or more components. In other words, as would be apparent to one of ordinary skill in the art after reading this description, the various features and functionality described herein may be implemented in any given application. They can be implemented in one or more separate or shared components in various combinations and permutations. Although various features or functional elements may be individually described or claimed as separate components, it should be understood that these features/functionality can be shared among one or more common software and hardware elements. Such a description shall not require or imply that separate hardware or software components are used to implement such features or functionality.

[0111] Where components are implemented in whole or in part using software, these software elements can be implemented to operate with a computing or processing component capable of carrying out the functionality described with respect thereto. One such example computing component is shown in FIG. **7**. Various embodiments are described in terms of this example-computing component **700**. After reading this description, it will become apparent to a person skilled in the relevant art how to implement the application using other computing components or architectures.

[0112] Referring now to FIG. **7**, computing component **700** may represent, for example, computing or processing capabilities found within a self-adjusting display, desktop, laptop, notebook, and tablet computers. They may be found in hand-held computing devices (tablets, PDA's, smart phones, cell phones, palmtops, etc.). They may be found in workstations or other devices with displays, servers, or any other type of special-purpose or general-purpose computing devices as may be desirable or appropriate for a given application or environment. Computing component **700** might also represent computing capabilities embedded within or otherwise available to a given device. For example, a computing component might be found in other electronic devices such as, for example, portable computing devices, and other electronic devices that might include some form of processing capability.

[0113] Computing component **700** might include, for example, one or more processors, controllers, control components, or other processing devices. This can include a processor, and/or any one or more of the components making up vehicular knowledge network system **100** of FIGS. **1**A and **1**B and/or vehicle **300** of FIG. **3**. Processor **704** might be implemented using a general-purpose or special-purpose processing engine such as, for example, a microprocessor, controller, or other control logic. Processor **704** may be connected to a bus **702**. However, any communication medium can be used to facilitate interaction with other components of computing component **700** or to communicate externally.

[0114] Computing component **700** might also include one or more memory components, simply referred to herein as main memory **708**. For example, random access memory (RAM) or other dynamic memory, might be used for storing information and instructions to be executed by processor **704**. Main memory **708** may store instructions that, when executed by processor **704**, execute one or more operations of process **500** of FIG. **5** and/or process **600** of FIG. **6**. Main memory **708** might also be used for storing temporary variables or other intermediate information during execution of instructions to be executed by processor **704**. Computing component **700** might likewise include a read only memory ("ROM") or other static storage device coupled to bus **702** for storing static information and instructions for processor **704**.

[0115] The computing component **700** might also include one or more various forms of information storage mechanism **710**, which might include, for example, a media drive **712** and a storage unit interface **720**. The media drive **712** might include a drive or other mechanism to support fixed or removable storage media **714**. For example, a hard disk drive, a solid-state drive, a magnetic tape drive, an optical drive, a compact disc (CD) or digital video disc (DVD) drive (R or RW), or other removable or fixed media drive might be provided. Storage media **714** might include, for example, a hard disk, an integrated circuit assembly, magnetic tape, cartridge, optical disk, a CD or DVD. Storage media **714** may be any other fixed or removable medium that is read by, written to or accessed by media drive **712**. As these examples illustrate, the storage media **714** can include a computer usable storage medium having stored therein computer software or data.

[0116] In alternative embodiments, information storage mechanism **710** might include other similar instrumentalities for allowing computer programs or other instructions or data to be loaded into computing component **700**. Such instrumentalities might include, for example, a fixed or removable storage unit **722** and an interface **720**. Examples of such storage units **722** and interfaces **720** can include a program cartridge and cartridge interface, a removable memory (for example, a flash memory or other removable memory component) and memory slot. Other examples may include a PCMCIA slot and card, and other fixed or removable storage units **722** and interfaces **720** that allow software and data to be transferred from storage unit **722** to computing component **700**.

[0117] Computing component **700** might also include a communications interface **724**. Communications interface **724** might be used to allow software and data to be transferred between computing component **700** and external devices. Examples of communications interface **724** might include a modem or soft modem, a network interface (such as Ethernet, network interface card, IEEE 802.XX or other interface). Other examples include a communications port (such as for example, a USB port, IR port, RS232 port Bluetooth® interface, or other port), or other communications interface. Software/data transferred via communications interface **724** may be carried on signals, which can be electronic, electromagnetic (which includes optical) or other signals capable of being exchanged by a given communications interface **724**. These signals might be provided to communications interface **724** via a channel **728**. Channel **728** might carry signals and might be implemented using a wired or wireless communication medium. Some examples of a channel might include a phone line, a cellular link, an RF link, an optical link, a network interface, a local or wide area network, and other wired or wireless communications channels.

[0118] In this document, the terms "computer program medium" and "computer usable medium" are used to generally refer to transitory or non-transitory media. Such media

may be, e.g., memory **708**, storage unit **720**, media **714**, and channel **728**. These and other various forms of computer program media or computer usable media may be involved in carrying one or more sequences of one or more instructions to a processing device for execution. Such instructions embodied on the medium, are generally referred to as "computer program code" or a "computer program product" (which may be grouped in the form of computer programs or other groupings). When executed, such instructions might enable the computing component **700** to perform features or functions of the present application as discussed herein.

[0119] It should be understood that the various features, aspects and functionality described in one or more of the individual embodiments are not limited in their applicability to the particular embodiment with which they are described. Instead, they can be applied, alone or in various combinations, to one or more other embodiments, whether or not such embodiments are described and whether or not such features are presented as being a part of a described embodiment. Thus, the breadth and scope of the present application should not be limited by any of the above-described exemplary embodiments.

[0120] Terms and phrases used in this document, and variations thereof, unless otherwise expressly stated, should be construed as open ended as opposed to limiting. As examples of the foregoing, the term "including" should be read as meaning "including, without limitation" or the like. The term "example" is used to provide exemplary instances of the item in discussion, not an exhaustive or limiting list thereof. The terms "a" or "an" should be read as meaning "at least one," "one or more" or the like; and adjectives such as "conventional," "traditional," "normal," "standard," "known." Terms of similar meaning should not be construed as limiting the item described to a given time period or to an item available as of a given time. Instead, they should be read to encompass conventional, traditional, normal, or standard technologies that may be available or known now or at any time in the future. Where this document refers to technologies that would be apparent or known to one of ordinary skill in the art, such technologies encompass those apparent or known to the skilled artisan now or at any time in the future.

[0121] The presence of broadening words and phrases such as "one or more," "at least," "but not limited to" or other like phrases in some instances shall not be read to mean that the narrower case is intended or required in instances where such broadening phrases may be absent. The use of the term "component" does not imply that the aspects or functionality described or claimed as part of the component are all configured in a common package. Indeed, any or all of the various aspects of a component, whether control logic or other components, can be combined in a single package or separately maintained and can further be distributed in multiple groupings or packages or across multiple locations.

[0122] Additionally, the various embodiments set forth herein are described in terms of exemplary block diagrams, flow charts and other illustrations. As will become apparent to one of ordinary skill in the art after reading this document, the illustrated embodiments and their various alternatives can be implemented without confinement to the illustrated examples. For example, block diagrams and their accompanying description should not be construed as mandating a particular architecture or configuration.

What is claimed is:

1. A method comprising:

detecting a performance result of first guidance performed by a first vehicle in a first driving environment that differs from an expected result associated with the first guidance associated with a second driving environment that corresponds to the first driving environment;

identifying behavior executed by the first vehicle associated with the detected performance result based on a comparison between the first driving environment to the second driving environment; and

based on detecting that a second vehicle is executing the identified behavior, generate second guidance to mitigate the identified behavior being executed by the second vehicle.

2. The method of claim **1**, further comprising:

determining that the second driving environment corresponds to the first driving environment based on a first set of contextual features associated with the first driving environment comprising a threshold amount of contextual features comprised in a second set of contextual features associated with the second driving environment.

3. The method of claim **2**, wherein the first set of contextual features comprises at least one of static features and dynamic features obtained from the first driving environment.

4. The method of claim **1**, wherein detecting a performance result comprises:

after the first vehicle performs the first guidance, receiving information representative of the performance result of the first guidance; and

comparing the performance result to the expected performance result.

5. The method of claim **1**, wherein identifying the behavior comprises:

inferring a contrasting contextual feature based on comparing a first set of contextual features associated with the first driving environment to a second set of contextual features of a second set of contextual factors associated with the second driving environment.

6. The method of claim **5**, wherein the contrasting contextual feature is a contextual feature that differs between the first set of contextual features and the second set of contextual features.

7. The method of claim **5**, inferring a contextual feature difference comprises:

identifying one or more contextual features included in the first set of contextual features that are absent from the second set of contextual features.

8. The method of claim **5**, inferring a contextual feature difference comprises:

identifying one or more contextual features included in the second set of contextual features that are absent from the first set of contextual features.

9. The method of claim **5**, wherein the contrasting contextual feature comprises a dynamic feature.

10. The method of claim **5**, wherein mitigating the identified behavior being executed by the second vehicle comprises mitigating the inferred contrasting contextual feature.

11. The method of claim **1**, wherein the second guidance comprises coordination between a plurality of vehicles within a third driving environment in which the second

vehicle is traveling, wherein the coordination is configured to mitigate the identified contrasting behavior of the second vehicle.

12. An apparatus of a vehicular knowledge network, the apparatus comprising:

a memory storing instructions; and

a processor communicably coupled to the memory storing and configured to execute the instructions to:

obtain a performance result of first guidance performed by a first vehicle in a first driving environment, wherein the first guidance is associated with a second driving environment that corresponds to the first driving environment;

determine that the performance result differs from an expected result associated with the first driving environment;

based on the determination, infer behavior of the first vehicle based on a comparison between the first driving environment to the second driving environment; and

based on detecting that a second vehicle is executing the identified behavior, generate second guidance configured to mitigate the inferred behavior being executed by the second vehicle.

13. The apparatus of claim **12**, wherein the apparatus is one of a vehicle and a server.

14. The apparatus of claim **12**, wherein inferring the behavior of the first vehicle comprises:

inferring a contrasting contextual feature based on comparing a first set of contextual features associated with the first driving environment to a second set of contextual features of a second set of contextual factors associated with the second driving environment.

15. The apparatus of claim **14**, wherein the contrasting contextual feature is a contextual feature that differs between the first set of contextual features and the second set of contextual features.

16. The apparatus of claim **14**, wherein the contrasting contextual feature comprises a dynamic feature.

17. A system comprising:

a memory storing instructions; and

a processor configured to execute the instructions to:

identify driving behavior of a first vehicle in a first driving environment that deviates from expected driving behavior based on the first vehicle executing guidance; and

generate compensation guidance configured to mitigate the identified driving behavior being performed by a second vehicle.

18. The system of claim **17**, wherein the guidance is knowledge-based guidance obtained based on a determination that a first set of contextual features associated with the first driving environment correspond to a second set of contextual features associated with the knowledge-based guidance.

19. The system of claim **18**, wherein identifying the driving behavior comprises determining a contextual feature that differs between the first set of contextual features and the second set of contextual features.

20. The system of claim **17**, wherein the compensation guidance comprises coordination between a plurality of vehicles within a second driving environment in which the second vehicle is traveling, wherein the coordination is configured to mitigate the identified driving behavior of the second vehicle.

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